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PUBLICATIONS OF THE GEOLOGICAL SOCIETY OF AMERICA

Regular Publications

The Society issues annually a single serial octavo publication entitled Bulletin of the Geological Society of America. The first twenty volumes of this serial consist of *proceedings* and *memoir brochures*, the former containing the records of meetings, with abstracts and short papers, list of Fellows, etcetera, and the latter embracing larger papers accepted for publication. Beginning with volume 21, the Bulletin will be issued in four parts per year (volume), at intervals of three months each. A small supply of authors' separates of the longer articles will be kept for sale by the Secretary.

The Bulletin is sold at the following prices: To Fellows, institutions, libraries, and persons residing outside of North America, seven dollars and fifty cents ($7.50) per volume; to persons in North America not Fellows of the Society, ten dollars ($10.00) per volume (the same amount as the annual dues of the Fellows). These prices cover cost of transmission to all parts of the globe. No reduction is made to dealers. Orders should be addressed to the Secretary, whose address is care of the American Museum of Natural History, New York, N. Y., and drafts and money orders should be made payable to *The Geological Society of America.*

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Proceedings of the Twenty-first Annual Meeting, held at Baltimore, Maryland, December 29, 30, and 31, 1908. E. O. Hovey, *Secretary*	607–749	102–111	1–3	1.80	2.70

Irregular Publications

In the interest of exact bibliography, the Society takes cognizance of all publications issued wholly or in part under its auspices. Each author of a memoir receives 30 copies without cost, and is permitted to order any additional number at a slight advance on cost of paper and presswork; and these separate brochures are identical with those of the editions issued and distributed by the Society. Contributors to the proceedings are also authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork ; but such separates are bibliographically distinct from the brochures issued by the Society.

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CORRECTIONS AND INSERTIONS

All contributors to volume 20 have been invited to send corrections and insertions to be made in their papers, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention :

Page 1, line 2 from bottom ; *for* "glad to have" *read* glad to leave
" 37, line 20 from top; *for* "1822" *read* 1882
" 60, line 7 from top; *for* "Halfield" *read* Halfeld
" 67, line 17 from bottom ; *for* "XVII" *read* XVIII
" 72, *omit* second Katzer title on "Phytopaleontologie"
" 98, line 26 from bottom ; *for* "Petro" *read* Pieto
" 130, line 20 from bottom ; *for* "*Belonstomus*" *read* Belonostomus
" 130, line 18 from bottom ; *for* "Rhacolepsis Alfersii" *read* Rhacolepis Olfersi
" 130, lines 16–17 from bottom ; *for* "Rhacolepsis" *read* Rhacolepis
" 130, line 15 from bottom, *for* "Cladacylus" *read* Cladocyclus
" 160, line 20 from bottom, *for* "cimpilation" *read* compilation
" 196, *insert* footnote : A further note on the geometry of faults will appear in volume 21

Page 350, line 7 from bottom ; *for* "plate 21, figure 2, and plate 22, figure 1," *read* plate 21, figure 1, and plate 22, figure 2

Page 350, last line ; *for* "plate 22, figure 2," *read* plate 22, figure 3
" 372, *invert* figure 4
" 375, line 11 from top ; *for* "axis" *read* axes
" 380, *insert* footnote : * The absence of planes of symmetry (vertical as usually held) in the simple pyramids of the axial classes is not always apparent to the student. It is recommended to use drawings and models showing combinations of pyramids of several orders, when the absence of such planes of symmetry becomes at once apparent and the distinction between the symmetry of the axial and hedral classes is clearly seen.

Page 380, line 11 from top ; *for* "plates I and II" *read* plates 31 and 32
" 381, line 10 from bottom, *for* "rotation. In the" *read* rotation, in the
" 381, line 5 from bottom ; *for* "axis—producing" *read* axis, producing
" 385, line 20 from top ; *for* "It is elementary" *read* It is simple
" 388, line 2 from top ; *for* "un-" *read* uni-
" 422, line 21 from top ; *for* "indicate" *read* indicated

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 20, PP. 1-132 FEBRUARY 12, 1909

BIBLIOGRAPHY OF THE GEOLOGY, MINERALOGY, AND PALEONTOLOGY OF BRAZIL*

BY JOHN C. BRANNER

(*Presented by title before the Society December 27, 1905*)

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INTRODUCTION

No comprehensive bibliography of the geology of Brazil has hitherto been attempted. M. de Margerie, in his *Catalogue des Bibliographies Géologiques,* published in Paris in 1896 by the Congrès Géologique International, mentions six papers upon geologic subjects, each of which contains references to Brazilian geology; but none of these lists makes any pretense of being a bibliography of the geology of Brazil. In 1881 the Bibliotheca Nacional, at Rio de Janeiro, published its important *Catalogo da Exposição da Historia do Brazil* in two large volumes. One of these volumes contains a list of the books and papers in the Bibliotheca Nacional that relate to the geology of Brazil, and included in this are many titles of works belonging to private individuals and not belonging to the library at that time. That is the nearest approach that has yet been made to a bibliography of the geology of Brazil. The list was necessarily imperfect; omitting the manuscripts and papers upon mineral waters, it contained only one hundred and twelve titles. A bibliography of the Mesozoic invertebrate paleontology of South America is given on pages 3 to 6 of Dr C. A. White's *Contribuições á Paleontologia do Brazil,* published at Rio de Janeiro in 1887. That list contains twenty-four titles.

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*An incomplete edition of this bibliography was published in the *Archivos do Museu Nacional do Rio de Janeiro,* vol. XII, in 1903. The proofs, however, were not seen by the author and many serious errors were overlooked by the printers. The great number of titles added, the corrections made, and the growing interest in the geology of Brazil have encouraged the Geological Society of America to publish the present list.

Dr M. A. R. Lisboa, one of the ablest of the younger Brazilian geologists, has now begun the publication of an annual annotated bibliography of the geology of Brazil in the *Annaes da Escola de Minas.* The author is glad to have future work on the subject in his able hands.

In 1901, the Bureau of American Republics published at Washington "A list of books, magazine articles, and maps relating to Brazil, 1800-1900," prepared by P. Lee Phillips, 8°, 145 pages. That list includes many titles upon geology and geography, but these articles are not distinguished from others, and, so far as they relate to geology, there are more omissions than titles.

The present bibliography contains over 2,000 titles, not counting abstracts, notices, and reviews.

Owing to the poverty of literature upon the geology of Brazil, many books of travel and exploration are included that make no pretense of being works upon geology, but which contain notes upon the subject of more or less value.

But though the number of titles is over 2,000, the bulk of them treat of the geology of Brazil only at second or third hand. The original papers from which most of these references are taken were written by a few men, the most important contributions being made by Agassiz, Clarke, Derby, Eschwege, Gorceix, Hussak, Lund, Rathbun, C. A. White, and Woodward, while the field work from which these results have been obtained was done by still fewer. Some of these men have also done a vast amount of work in cognate branches of science. Lund, for example, worked on zoology and botany, as well as on geology; and the papers of Lütken, Rheinhardt, and Warming on botany and zoology are the direct outcome of Lund's work in Brazil.

This list emphasizes the fact that the great bulk of the geologic work in Brazil has been done by two men—Eschwege and Derby. These men are noteworthy both for the amount and the character of their work. Eschwege's results were mostly published in German, and have therefore not been as accessible to Brazilian students as if they had been published in Portuguese or French.

Fortunately the results of Derby's work have been published in Portuguese as well as in English, and his influence upon geologic work in Brazil has been correspondingly important. Moreover, Derby's influence has extended even further than the long list of his valuable papers would indicate, for almost every modern writer upon the geology of Brazil has been inspired by Derby's work, and not a few of them have based their conclusions almost entirely upon data furnished by him.

Mr Henri Gorceix, for several years director of the Escola de Minas at Ouro Preto, has also done much to arouse an interest in the mineralogy of Brazil and in mining engineering. Several of his students are now among the most active and efficient workers on the geology of the country.

The present bibliography is chiefly an author's list arranged alphabetically. When there are several titles credited to one author, they are arranged chronologically.

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PRESENT PHASE OF THE PLEISTOCENE PROBLEM IN IOWA[1]

PRESIDENTIAL ADDRESS BY SAMUEL CALVIN

(Read before the Society December 29, 1908)

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INTRODUCTION

More than once your speaker has had occasion to say that Iowa was exceptionally fortunate in its location with reference to the movements and marginal limits of the successive ice invasions of the Glacial epoch, and that the state therefore offers unusual facilities for the study of the relative age and differential characters of the several sheets of drift. It is not to be understood from this, however, that in the favored area selected for discussion there are no unsettled Pleistocene problems. Important questions, many of them, are still waiting for solution; but while knowledge is admittedly incomplete in many particulars, it may be worth the while at this stage in the interpretation of Pleistocene records to set out the points that seem to be indicated with a fair degree of clearness. In the discussion which is to follow no attempt will be made to give an historical outline of the growth of knowledge relative to the problems under consideration, such as would be appropriate in an address dealing finally with the subject; nor will any effort be made to assign the degree of credit which belongs severally to the masters who have worked so effectively and so illuminatingly in the Pleistocene field. It will be enough to say that Pleistocene geology, as represented in Iowa, is indebted to a host of men, among whom may be mentioned Chamberlin, McGee, Bain, Upham, Leverett, Udden, Beyer, Macbride, Shimek, and Savage; while of men who have contributed to our knowledge of Pleistocene conditions outside of Iowa the number is still larger. Noteworthy, epoch-making, have been the scholarly contributions of such students of Canadian geology as Hinde, Coleman, and Dawson.

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[1] Manuscript received by the Secretary of the Society January 11, 1909.

The fact that within the limits of Iowa at least five distinct drift sheets are clearly differentiated, a number greater than may be readily distinguished in any corresponding area elsewhere, affords some justification for limiting the discussion to so small a portion of the glaciated area. The problems of this limited field, however, are the problems of the continent, so far as the age of ice is concerned.

Pleistocene Problem of Twenty Years ago and of Today

Less than twenty years ago there was at least one eminent geologist on this side of the Atlantic who denied the evidence of any glacial invasion of any of the present habitable portions of North America. There were many who admitted the evidence of one, but only of one, episode of glaciation, and some of this class still survive. A few men whom we all honor were laboriously collecting facts which proved that glaciers had overridden portions of the continent at least twice; and they discussed phases of glaciation which, in accordance with the best knowledge of the time, were known as the "First" and "Second" glacial epochs. Upper and Lower till became familiar terms in the literature of Pleistocene geology. Now we point to evidence showing five ice invasions, possibly six; and only a few, if any, are left to question the adequacy of the evidence. As stated at the outset, the location of Iowa with reference to the known ice movements was exceptionally favorable. The two earlier sheets passed across the state, covering the whole surface except the small part of the Driftless area which lies in the northeastern corner. Terminal margins of the known three later sheets come within the limits of Iowa, and the movements were so distributed that no one of the ice lobes obscured the records of its predecessors. There are, therefore, miles upon miles of well defined border lines along which it is possible to compare directly the characteristics of one drift sheet with another; and there are interglacial deposits bearing testimony to the nature of the faunas and floras and climatic conditions which characterized the central portions of the continent during the long, mild intervals between the stages of glaciation. It is the purpose of this address to set forth what the Pleistocene records of such an area more or less definitely prove.

First and Second Glacial Epochs and First interglacial Interval

GENERAL CHARACTERISTICS

During the early Pleistocene, as already noted, there were two stages of glaciation which affected larger areas in Iowa than any of those which followed. So far as present knowledge goes, these were the real first and second Glacial epochs of which we have discovered records in the interior of the continent; but later investigations, as has happened before, may change the ordinal positions here assigned them. No conceivable discoveries, however, can possibly modify the fact that these two invasions were distinct glacial episodes, separated one from the other by a long interval; for here are two sheets of drift distinctly different, recording the coming and going of two ice caps, while soil bands, weathered zones, buried peat bogs, forest beds, pond silts, and stream gravels lying between the till sheets tell of interglacial conditions. The widely distributed peats and forests of the intercalated beds furnish a record of the plants which flourished during the interval; and within the last four months the gravels between the older drifts in Harrison, Monona, and other western counties have contributed the first important information from the area under consideration concerning the first interglacial fauna.

The earlier of the two older drifts is known in the geology of Iowa as the pre-Kansan or sub-Aftonian, and the later of the two, adopting the name proposed by Chamberlin, is the Kansan. Whether the pre-Kansan should be correlated with the Albertan of the north, or with the Jerseyan of the east, or with anything else now known in America or in Europe, is a question that need not be discussed. It is enough for the present that here are two sheets of drift recording two distinct stages of glaciation, with abundant evidence of an interval between them.

PRE-KANSAN OR SUB-AFTONIAN DRIFT

The pre-Kansan is dark blue, almost black in color. It has a habit peculiarly its own of breaking into small fragments or crumbling into finer particles on continued exposure. At the classic locality near Afton Junction this older drift is exposed in the west bank of Grand river, a mile below the station, and is overlain by more than 30 feet of water-laid gravels which were at one time worked for railway ballast. Overlying the gravels is a heavy deposit of typical Kansan till. The same gravels are exposed in a great ballast pit at Afton Junction, from which locality came the name "Aftonian," given by Chamberlin to the gravels as well as to the entire interval of which they form part of the record. Four miles farther east, near Thayer, is another pit of Aftonian gravels. At all the localities named the Aftonian beds are covered with from 20 to 30 feet of characteristic Kansan (plate 1, figure 1).

KANSAN DRIFT

The Kansan differs from the pre-Kansan physically. It is light blue or gray in color when unweathered; it is cut by numerous intersecting, vertical joints, and it breaks into large, irregularly shaped angular blocks. That there are physical differences may be demonstrated wherever there are opportunities for comparison, but a concrete case may be cited in the section illustrated by Savage in his report on Tama county.[2] Here the two older drifts are separated by a mere thin soil band. The lower, as shown in the figure, is compact but relatively plastic, and the steam shovel passing through it left the imprint of its cutting margin; the bed above the Aftonian soil, hard almost as sun-baked bricks, and jointed vertically, yielded to the force of the shovel by breaking into irregular, prismatic blocks. Physical differences, constant and consistent, mark these two beds of till as distinct (plate 1, figure 2).

AFTONIAN INTERVAL

The Aftonian was a real interglacial interval. It was a long interval, but the data which might furnish a basis for estimating its actual or comparative length are as yet wanting. With the possible exception of the "forest bed" which McGee, in his early work on the Pleistocene, had found everywhere between his "Upper and Lower till," the gravels at Afton Junction and Thayer were the first of the Aftonian deposits to be

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[2] Geology of Iowa, vol. xiii, page 231.

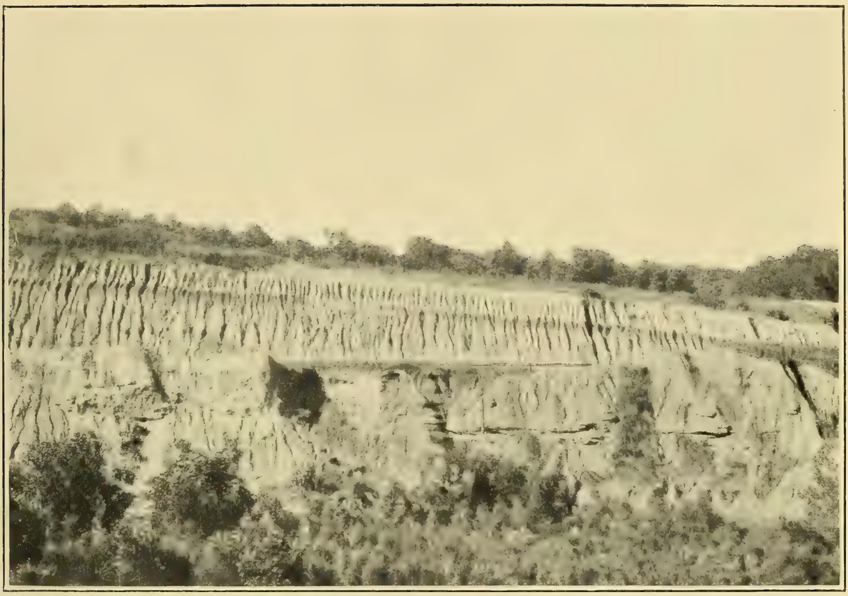

FIGURE 1.—VIEW IN THE GRAVEL PIT AT AFTON JUNCTION, IOWA

Showing (1) Aftonian gravels more than 20 feet in thickness, rising a few feet above the railway grade; (2) Kansan drift much weathered and stained in the upper zone; (3) loess.

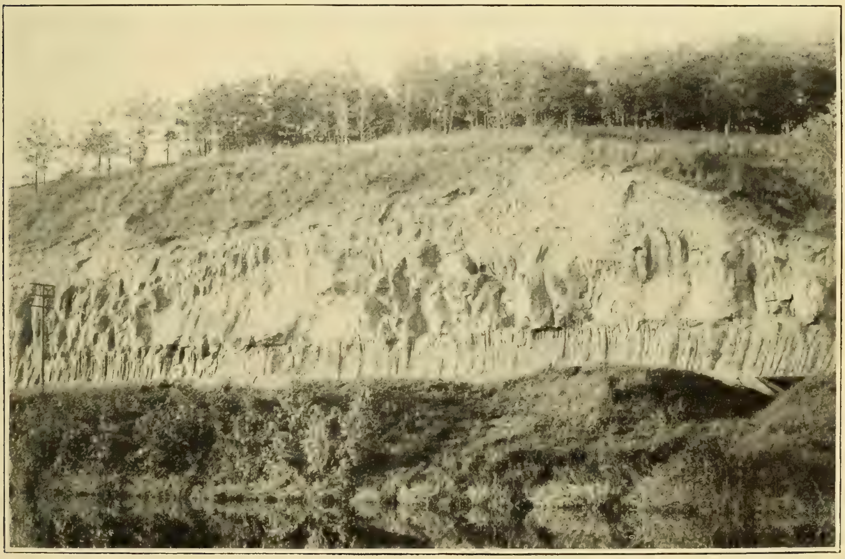

FIGURE 2.—SECTION IN RAILWAY CUT IN TOLEDO TOWNSHIP, TAMA COUNTY, IOWA

Showing well defined soil-band between the pre-Kansan and the Kansan drifts

GLACIAL PHENOMENA AT AFTON JUNCTION AND IN TAMA COUNTY, IOWA

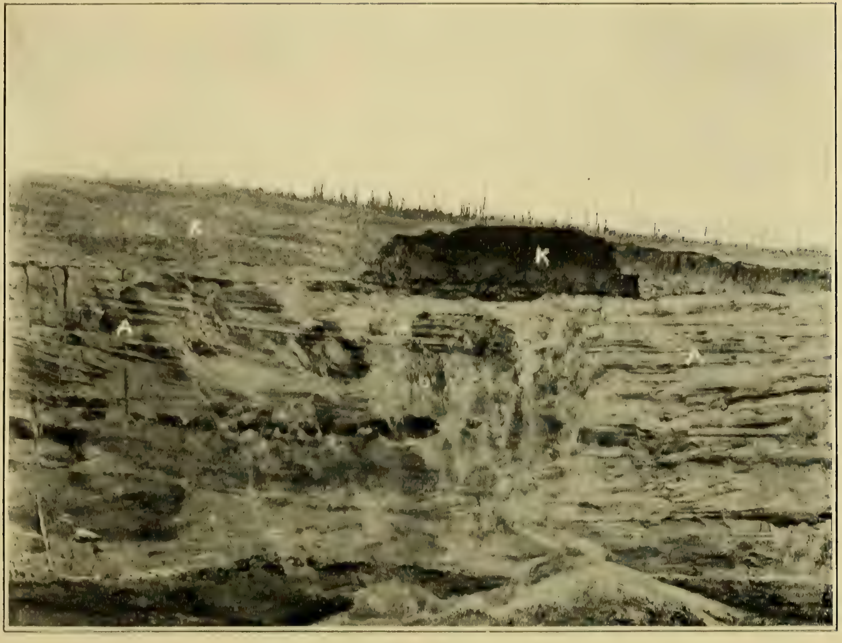

FIGURE 1.—COX GRAVEL PIT NEAR MISSOURI VALLEY, IOWA

Exposing cross-bedded sands and gravels of Aftonian age beneath Kansan drift. These gravels have yielded a large number of mammalian and molluscan remains

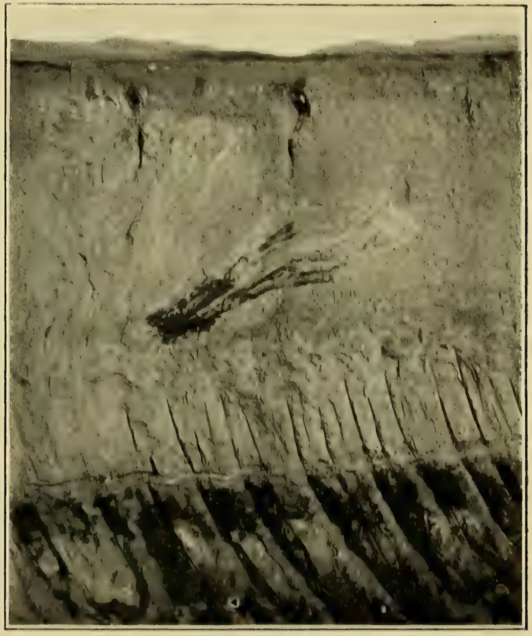

FIGURE 2.—SECTION IN THE OELWEIN CUT

When fresh this cut showed (1) Aftonian peat with fresh moss and well-preserved trunks of trees; (2) Kansan drift with two large "sand boulders," derived from Aftonian beds; (3) Iowan drift.

GLACIAL PHENOMENA NEAR MISSOURI VALLEY AND OELWEIN, IOWA definitely recognized. They were the first of these deposits to be assigned to their true position in the Pleistocene column. In themselves these gravels afforded little information concerning the time interval to which they belong, farther than that the pre-Kansan ice had disappeared from the region and that great floods, distributing the usual terrace materials, poured along the drainage courses. In a paper on the Aftonian gravels, in the Proceedings of the Davenport Academy of Sciences, volume X, it was assumed that the floods carrying the materials of which the beds are composed had their origin in the melting of the pre-Kansan ice, and that these deposits represented simply the closing phase of the pre-Kansan stage of glaciation. The assumption was based wholly on the ground that it was difficult otherwise to account for streams of such volume and persistency as would be required to transport and deposit the enormous quantities of gravel found in Union county. Now, however, it seems that investigations made by Shimek during the past four months may make it necessary to modify the view expressed in the Davenport Academy paper. Similar materials, quite as extensive as the beds at Afton Junction and Thayer, lying between the dark pre-Kansan below and typical Kansan above (plate 2, figure 1), are found along the Boyer, the Soldier, the Little Sioux, the Maple, and practically all the streams which drain the western slope of Iowa. In these new localities the Aftonian gravels have yielded the remains of a fauna representing river mollusks of modern species on the one hand and extinct terrestrial mammals on the other. Both mollusks and mammals are found in such abundance, at such widely scattered localities, and in such a state of preservation as to make it certain that the fauna was contemporaneous with the deposition of the gravels. They are not remains washed out of previous glacial or preglacial formations. The mammals include forms which have been referred by some recent American writers to *Elephas primigenius* and *Elephas imperator;* there is the common mastodon, *Mammut americanum;* there are two horses resembling the *Equus complicatus* and *Equus occidentalis* of Leidy; a large stag related to *Cervalces;* an undetermined cavicorn ruminant and one or two other unidentified forms. All the probiscideans are represented by teeth, and in addition to the teeth there are the lower jaw of the large elephant, the left ramus and symphysis of the mastodon, a perfect tibia, a nearly perfect humerus, a femur nearly four feet in length, and yet lacking the proximal end; a scapula which was perfect when taken from the pit, but was allowed to go to pieces for lack of care; fragments of tusks up to four feet in length, a few vertebræ, some pieces of the pelvis and unrecognized fragments. There are a number of teeth from both horses, besides a large collection of equine bones which may belong to either of the two species. There are vertebræ, scapulæ, and calcanea; nearly all the limb bones are represented, including metapodials and phalanges. The large amount of the material and its unexpectedly perfect state of preservation, these are the impressive facts, and these indicate very clearly that the fossils are not mere chance intrusions, but are the remains of a fauna which was living in the region at the time the gravels were accumulating. Furthermore, it will be evident that the presence of this fauna, whether we take into consideration either its molluscan or its mammalian phase, is inconsistent with the view that the floods indicated by the deposits were fed by melting glaciers. When this fauna lived and the gravels were deposited there had been time enough since the disappearance of the pre-Kansan ice to allow the region to become clothed with an abundant vegetation suitable for the support of the elephant and the horse; and the temperature of the streams did not preclude the presence of types of mollusks which find a congenial habitat in the rivers of modern Iowa. The Afton Junction-Thayer beds have yielded fossils, quite a number; but among these are such forms as Favosites from the Silurian and Placenticeras from the Upper Cretaceous. Among the other things there occurred some foot bones of a small, slender-limbed horse less than half the height of our domestic species. The stage of equine development indicated by the bones showed that the animal could not be older than the Pliocene; but it was assumed that, like the other fossils from the same beds, it must be pre-Glacial. In the light of the new finds in Harrison and Monona counties we may conclude that this beautiful little Equus was probably contemporary with the deposition of the gravels, and that there may have been at least three species of Aftonian horses.

Concerning the precise age of these widely distributed gravels between the Kansan and the pre-Kansan, it may be said that the Aftonian faunas show that they were not laid down at the beginning of the interval, when the earlier ice-cap was melting. Extensive weathering and alteration of the materials, especially in the upper zone, show that they were not deposited at the close of the interval, when the Kansan ice was advancing. Forest material and remnants of an old soil, observed by Chamberlin and McGee between the gravels and the overlying drift, support the conclusion based on weathering. All lines of evidence now indicate that the beds in question record conditions which existed at some time during the progress of the interval, neither at its beginning nor at its close, but in the light of present knowledge the precise age of the deposits can not be more definitely stated.

The soil band in the railway cut near Tama, already noted, is one of many instances of the same kind and it tells the story of an interglacial interval as clearly and forcefully as the gravels and their remarkable faunas. Interglacial peat beds confirm the testimony of the old soils and buried gravels. One of the best known examples of peat at the Aftonian horizon is that in the Oelwein cut. The organic deposit is three feet in thickness; it contains the remains of a tamarack forest, together with great quantities of pressed moss, almost as fresh as when it grew; the whole is underlain by dark pre-Kansan and covered with 20 feet of Kansan and Iowan till. The Aftonian peat bed described by Savage in the eleventh volume of the Proceedings of the Iowa Academy of Science is, in some respects, even more important than that at Oelwein; the fauna and the flora of the deposit have been worked out in greater detail. Additional testimony to the same effect is found in the buried forests encountered in digging farm wells over practically the whole of Iowa. Facts relating to this phase of the subject, so far as concerns some of the northeastern counties of the state, were collected by McGee, and are set forth in great fullness and with masterly clearness in his memorable paper, *"The Pleistocene History of Northeastern Iowa."* The Aftonian, more than any other of the interglacial intervals, was a time of luxuriant forests, and forest beds are at present unknown at any horizon in the region studied by McGee except that between the Kansan and pre-Kansan drifts. In view of the evidence, clear and positive, and multiplied over and over again, we can but repeat that the Aftonian was a real interglacial interval, an interval of long duration, an interval of moist climate and swollen streams, an interval when the winters' cold was not so severe or the snowfall so excessive as to preclude the continued occupation of the region by the great stag, the horse, the mastodon, and the elephant—an interval when the modern types of river mollusks flourished in the streams of Iowa.

PHYSICAL RELATION OF THE KANSAN TO THE OLDER DEPOSITS

The Kansan till, which overlies the Aftonian beds, records what now appears to have been the maximum phase of Pleistocene glaciation. Kansan drift is superficial, except for a partial covering of loess over southern and western Iowa. Its physical properties, color, texture, and toughness, which have often been described, distinguish it readily from till of any other age. In some cases the Kansan ice plowed into the Aftonian gravels, broke them up while frozen, and transported masses varying in some of their dimensions from a few inches to more than one hundred feet. It follows, therefore, that sand and gravel boulders, derived from Aftonian beds and incorporated with other morainic detritus, are among the notable features of the Kansan drift, whether seen in the Oelwein cut in northeastern Iowa (plate 2, figure 2) or in the large cuts near Thayer, in the southwestern part of the state (plate 3, figure 1). Near Missouri valley, at one of the newly discovered exposures, there is a great mass of transported and badly distorted Aftonian, the full size as yet unknown, but it has been worked quite extensively as an independent gravel pit. The strata, originally horizontal and cross-bedded, are faulted and folded, and in some cases they are tilted through an angle of more than ninety degrees. On the side showing the greatest deformation the pit has been worked out up to a vertical wall of Kansan drift; and in this body of till, against which the gravels, standing on edge, suddenly end, we recognize the instrument used by the Kansan glacier in plowing into the Aftonian beds and breaking them into blocks. Here is a mass of deformed and displaced Aftonian, an enormous sand and gravel boulder, and here, in the exact position assumed while the work was being done, is the agent through which was transmitted the shove and the thrust recorded in the distorted gravels (plate 3, figure 2). Masses of the dark pre-Kansan, rolled and kneaded and showing the effect of the tremendous squeeze and push of a continental glacier, also occur as boulders embedded in the Kansan. These sharply defined masses of Aftonian gravels and pre-Kansan till, large or small, incorporated in the Kansan, add confirmation to the evidence, if confirmation is needed, that this till and these gravels existed as distinct geological formations before the Kansan ice invaded Iowa.

RELATIVE AGE OF KANSAN AND PRE-KANSAN

While the Kansan is younger than the pre-Kansan, younger than any of the Aftonian deposits, it is not possible to say, even approximately, how much younger it is. The gravels were greatly altered by weathering before the Kansan drift was deposited, the oxidation and kaolinization requiring time. It required time to clothe the cold, bare surface of the pre-Kansan drift with forests, and forests did grow luxuriantly, generations of them probably, during the Aftonian interval. The accumulation of the Aftonian peat required time. Time was needed for the development and distribution of the aquatic and terrestrial Aftonian faunas. But, granting all the time required for these things, it is still probable that the length of the Aftonian interval was equal to but a small part of post-Kansan time. If the time since the Kansan be represented by unity, the time since the pre-Kansan would be represented by one and a small fraction. On the other hand, the Kansan till is certainly very much older than any of the later drift sheets, and fortunately the data on

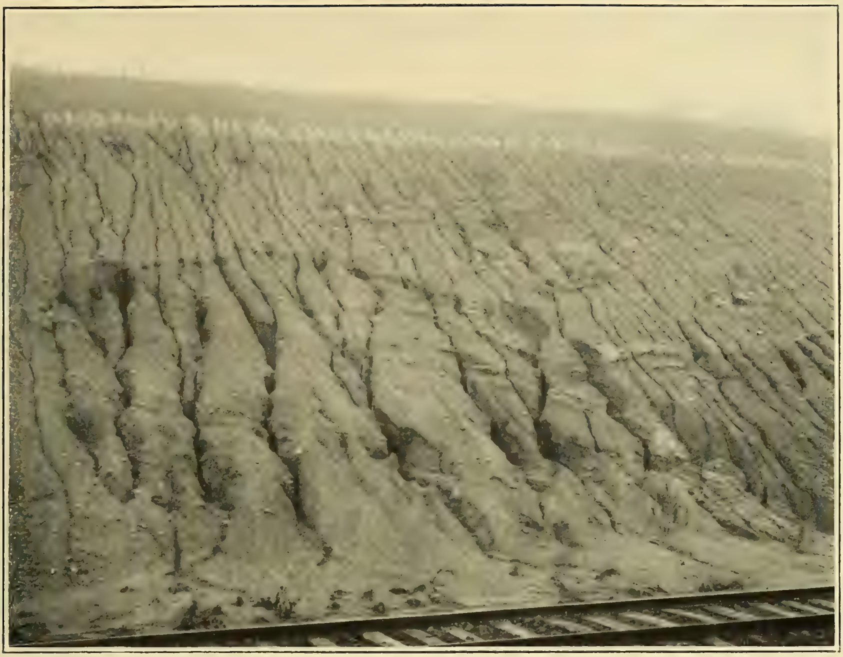

FIGURE 1.—VIEW IN RAILWAY CUT NEAR THAYER

Showing a moderately large mass of Aftonian gravel, with smaller "sand boulders" from the same formation, incorporated in the Kansan drift

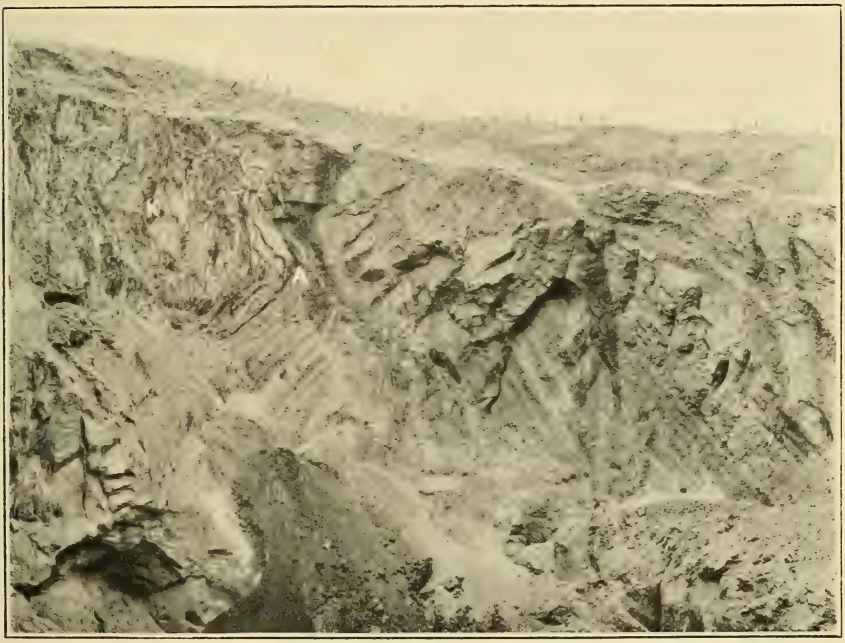

FIGURE 2.—THE MCGAVERN GRAVEL PIT NEAR MISSOURI VALLEY

Showing (A) a very large "sand boulder" of Aftonian gravel, crushed, faulted, and deformed, and (K) the face of a mass of Kansan drift, the agent through which the crushing was accomplished.

GLACIAL PHENOMENA NEAR THAYER AND MISSOURI VALLEY, IOWA

which estimates of relative age may be based are fuller and more satisfactory than in the case of the pre-Kansan intervals.

ILLINOIAN DRIFT AND THE YARMOUTH OR SECOND INTERGLACIAL INTERVAL

The drift which followed the Kansan, the third in the known order, is the Illinoian, and the interval between the Kansan and the Illinoian is the Yarmouth. For the last two names, Illinoian and Yarmouth, and for the first discussion of the records to which they are applied we are indebted to Leverett. The Yarmouth seems to have been the longest of the interglacial intervals. The Illinoian glaciation, which followed the Yarmouth, affected directly only a small part of Iowa. Ice from the Labradorean center came from the northeast, crossed the channel of the Mississippi, and pushed a broad lobe into a relatively small area in southeastern Iowa. If glaciers corresponding to the known Illinoian were developed in the Kewatin region, they terminated in that part of the glaciated area which was subsequently covered with Iowan or Wisconsin drift, or with both. Illinoian of Kewatin origin has not so far been anywhere recognized. The strip of territory occupied by the Illinoian drift west of the Mississippi river is rarely more than 25 miles in width, and is limited to portions of Scott, Muscatine, Louisa, Des Moines, and Lee counties. In this area it overlaps the Kansan, and at various points near the margin of the lobe wells have gone through Illinoian into Kansan, revealing a zone of weathering, a definite soil band, extensive alluvial deposits, and well developed peat beds between the two bodies of drift. The facts have been worked out by Leverett, and are recorded in volume V of the Proceedings of the Iowa Academy of Sciences and in his monograph on the Illinois glacial lobe. Owing to the greater recency of the Illinoian as compared with the Kansan, the amount of valley cutting since it was deposited has been much less than in the Kansan, and the opportunities for observing the Yarmouth interglacial deposits in natural exposures are fewer than in the case of the Aftonian. The Yarmouth, however, is a true interglacial interval. It had its forests and its terrestrial faunas, as shown by the sections near the village of Yarmouth, which Leverett has recorded. The faunas embraced some modern mammals, for the peat encountered in digging one of the wells furnished bones of the modern wood rabbit and the common skunk. The mammals of the Aftonian beds so far collected are all extinct.

The relative length of the Yarmouth interval may be determined approximately by comparing the changes which time has wrought in the Illinoian drift sheet with the changes recorded in the adjacent and subjacent Kansan. The great body of the Illinoian, where unaltered, is yellow in color; the Kansan, as already noted, is blue. The Illinoian surface shows practically no erosion, except at the margin or along the larger stream valleys; over more than three-fourths of its area there is little or none of the sculpturing effect of surface drainage. At its margin, or near the larger streams which have been successful in keeping their valleys scoured out, there is some water carving, but the narrow, rain-cut gulches are steep, and they terminate at most only a few miles back from the foot of the grade, in the uninvaded plateau. All the characteristics of the Illinoian may be studied between Durant and Davenport, or between Columbus Junction and Morning Sun or Mediapolis. Weathering, as expressed by oxidation, hydration, and kaolinization of feldspars, affected the deposit to a depth of 3 or 4 feet. Compare now with the Kansan. In the older drift the changes due to weathering, whatever the names employed to denote processes of alteration, have gone down to depths varying from 12 to 30 or 40 feet, and that in a stiffer and more impervious clay than the Illinoian. The whole surface over hundreds of square miles is carved by storm waters into well rounded ridges and deep, wide-open ravines. The lateral ravines on the side slopes of the larger drainage valleys have very gentle gradients as compared with those in the Illinoian, and they reach back into the interstream areas, up to the summits of the rounded divides. Excepting in a few limited localities where there are very wide or relatively low spaces between the larger systems of drainage, there is none of the original drift plateau left. In his paper in the Proceedings of the Iowa Academy of Sciences, volume V, Leverett cites evidence to show that quite an amount of erosion had probably taken place in the surface of the Kansan before the Illinoian drift was deposited. The amount of erosion indicated is much more than has been effected in the general surface of the younger of the two drifts we are comparing since the disappearance of the Illinoian ice. But even if we disregard this particular bit of evidence of probable pre-Illinoian erosion of the Kansan, it is still true that, under similar conditions as to proximity to the main drainage courses and altitude above them, the amount of erosion in the Kansan is very much more than twice as great as in the Illinoian. On the basis of erosion alone we are justified in concluding that the Yarmouth interval was longer than all post-Illinoian time.

Considering the effects of weathering and general alteration, the evidence leads to the same conclusion. The first few feet below the surface should undergo alteration rapidly. This zone is exposed more directly to the atmosphere, to storm waters, to thawing and freezing, to the chemical reactions of carbon dioxide, humic acids, and other products of decaying vegetation; to the direct and indirect effects of burrowing animals, such as gophers, ants, and earthworms; and changes may go on with comparative rapidity. Whatever the time required to produce weathering to a depth of 4 feet, the time required to bring about changes to a depth of 8 feet will be very much more than twice as great. The Kansan is altered to an average depth of more than 8 feet; the weathered zone of the Illinoian rarely exceeds 4 feet; again we conclude that the Yarmouth interval was more than equal to all post-Illinoian time.

THIRD INTERGLACIAL INTERVAL, THE SANGAMON

Another interglacial interval, the Sangamon of Leverett, followed the withdrawal of the Illinoian ice. There are no very satisfactory deposits of Sangamon age in Iowa, but the interval is very clearly represented at a number of points in Illinois. This interglacial horizon, like the Aftonian and the Yarmouth, is indicated by its buried forests, its soil and weathered zones, its pond silts, and its peat beds. One of the most instructive sections showing the relations of the Sangamon stage is seen in a railway cut on the Toledo, Peoria and Western railway, 7 miles east of Peoria. The exposure is described by Leverett in his monograph on the Illinois glacial lobe, and is illustrated in plate XI, figure B, opposite page 128, of the work cited. The section shows in ascending order (1) typical yellow Illinoian till; (2) stratified silt, evidently laid down in a quiet, shallow pond; (3) peat, with great quantities of tamarack roots, recording conditions which followed the silting up of the pond and its conversion into a marsh; (4) loess, probably Iowan or early Peorian; (5) Wisconsin drift, and (6) Wisconsin gravels. Numbers 2 and 3 represent the Sangamon. The weathered zone at the top of the Illinoian, and underneath loess which may be of Peorian age, is a feature seen at numberless points in Iowa as well as in Illinois, and represents changes which were wrought, in part at least, during the Sangamon interval. Muscatine, Montpelier, and Davenport may be named among the Iowa localities where this phase of the subject may be studied. At the brickyard east of Mud creek, in Muscatine, the Illinoian is overlain by beds of stratified sand which, there is little doubt, belong to the Sangamon; they may represent, however, only the beginning of the Sangamon, the melting phase of the Illinoian ice. In turn the sands are overlain by loess.

IOWAN DRIFT

EXTENT OF THE IOWAN

Following the Sangamon interval there was a recurrence of glacial conditions, and the Iowan drift, the fourth of the known till sheets, was distributed over a portion of the previously glaciated area. The Iowan ice, so far as it affected Iowa, came from the northwest, as the Kansan and the pre-Kansan had done in the earlier stages of the Pleistocene; but the Iowan glaciers stopped a long way short of the limits reached by their ancient predecessors from the Kewatin centers. The main body of the Iowan failed to reach Iowa. A broad lobe was all that passed the northern boundary of the state, and this covered an area approximately 100 miles in length from northwest to southeast and 80 miles in width. The area thus affected lies in the northeastern quarter of Iowa, in a region that had not been reached by the Illinoian. It was the eroded and weathered surface of the old Kansan, therefore, that this ice invaded and on which the Iowan was deposited. The latest observations show that within the limits of the area under discussion the Iowan nowhere touches or overlaps the Illinoian. Along a line drawn from Marshall county to the northwest corner of Worth the Iowan is itself overlapped by the younger Wisconsin.

RELATIVE AGE OF THE IOWAN

The Iowan is a very young drift when compared with the Illinoian. Its surface remains as the ice left it. Not even along the larger watercourses has it been trenched to any notable extent, as is so conspicuously the case in the Illinoian. Effects of erosion are practically zero, or they were about zero until the agriculturist came to disturb the adjustments of slope and run-off and vegetation, which maintained a fair degree of topographic stability. The opening of artificial drainage courses, the destruction of the prairie sod, and the general cultivation of the surface have resulted in more erosion during the last fifty years than had taken place under natural conditions during all the millenniums since this till was deposited. And yet, with all the help that destructive art has furnished, the surface as a whole remains essentially unchanged. If we may judge by the comparative erosion in the Iowan and the Illinoian, the Sangamon interval, though shorter than the Yarmouth, was fairly long. If the interval is measured by the comparative extent of the changes wrought by weathering, the conclusion is the same, but the conviction is stronger. The brown or red weathered zone of the Illinoian is from 3 to 4 feet in thickness. In the Iowan there is a deep, black soil developed on the surface, but changes due to weathering can not be recognized. In particular instances where the Iowan till is thin, the whole thickness of the deposits belonging to this stage is included in the humus layer; but where the thickness amounts to several feet, apart from the dark soil band there are no changes which can be measured or described. The till presents the same color and has the same composition from its most deeply buried parts up to the grass roots in the humus layer at the surface. The amount of weathering in the Iowan must be expressed by a number that is very near to zero. How many times greater must be the number which would fitly express the amount of Illinoian weathering which has affected a zone 3 or 4 feet in thickness? And if we had these numbers correctly determined, would their relative values correctly express the relative lengths of post-Illinoian and post-Iowan time? If so, the Sangamon was very long, and the Illinoian is many times as old as the Iowan. It may not be inappropriate here to say that the question of leaching is not emphasized in this discussion. The amount of lime carbonate present in any drift is a criterion of small value in determining its age. Quantitatively, the calcareous material included in the different drift sheets as an original constituent differed very greatly. For example, the Iowan drift was never as calcareous as the Kansan. There is very little limestone flour even in its deeper parts, and there are practically no limestone pebbles. Within the limestone areas of the region which it traversed, the Iowan ice seems to have been too thin to cut down to bedrock. All the characteristic materials which it carried, all except what may have been picked up from the Kansan, were probably derived from an area near the origin of the ice-sheet, an area of coarse crystalline rocks. On the other hand, the Wisconsin drift is charged to excess with limestone flour and limestone pebbles, greatly outranking in the matter of these constituents all the other glacial deposits of the Mississippi valley. Again, we find that the same till sheet varies in respect to lime content in different localities, the old Kansan having originally had vastly more calcareous material in the southwestern part of the state than in the northeast. Furthermore, the presence or absence of lime carbonate near the surface of any particular drift sheet may depend locally on movements of ground waters. Without movement there can be no transfer of the soluble contents of the drift from one place or from one zone to another. Again, a drift sheet may be never so young—it may have been finished but yesterday—but if the ice which transported it traversed a region containing nothing but siliceous rocks, the most industrious wielder of the acid bottle could get no reaction. The acid bottle may have its place, but it lacks something yet of being an instrument of precision when used to determine the relative age of drift. The bearing of all this is obvious, and it is all told to emphasize the point that, owing to its original composition, the superficial portion of the Iowan drift, or any other portion of it, for that matter, may give little or no reaction with acid; but the drift is nevertheless young. Measured by any trustworthy criterion, the Sangamon interval, though shorter than the Yarmouth, was long.

UNDULATING SURFACE OF THE IOWAN

The surface of the Iowan is more undulating than that of the Illinoian. The amount of material carried by the Iowan ice within the territory covered by the Iowan lobe was very small: the deposit is thin and meager as compared with the great thickness of the Kansan till; it is very much thinner than even the Illinoian. There was not enough of the Iowan completely to disguise the topography of the eroded surface upon which it was laid down. The thickness varies from zero on the summits of the old Kansan ridges to a probable maximum of 20 feet over the Kansan valleys. There are large spaces, scores of them, within the Iowan area where there is not now a trace of Iowan drift. The Iowan ice passed over them, but left none of its load. Such a space occupies a few square miles east and north of Independence, in Buchanan county. Another, a larger one, lies south of Lime creek, in Cerro Gordo county. There are many similar cases, especially near the marginal limits of the Iowan lobe, and all demonstrate the fact that Iowan drift may be absent from a fairly large area and present in all the area surrounding it. For example, the Iowan drift is absent for a mile or more east of Independence, but at the old Illinois Central gravel pit, 4 miles east of the city, the Iowan is about as well developed as it is anywhere in the state. Here the drift in question overlies weathered Buchanan gravels, post-Kansan in age, which have been worked for railway ballast; it varies from 1 foot to 8 feet in thickness (plate 4, figure 1). The meagerness of the Iowan till, even when normally present, and its entire absence from large areas which must have been covered with Iowan ice have made it very difficult in some localities to determine the exact position of the border of the Iowan lobe. The Iowan border, as drawn on the drift maps published in the reports of the Iowa Geological Survey, in the light of clearer knowledge of the peculiarities and behavior of the Iowan ice, will require a considerable amount of rectification.

INDIVIDUAL CHARACTERISTICS

Notwithstanding its meagerness and occasional absence, the Iowan drift exists, and it has its distinctive individual characteristics. It is light yellow in color, lighter than the Illinoian. It is less calcareous than any of the other drifts. Its characteristic boulders are large, light-colored, coarse-grained granites, rich in feldspar, and ranging from 10 or 12 to 40 or 50 feet in diameter. These great rough boulders, numerous

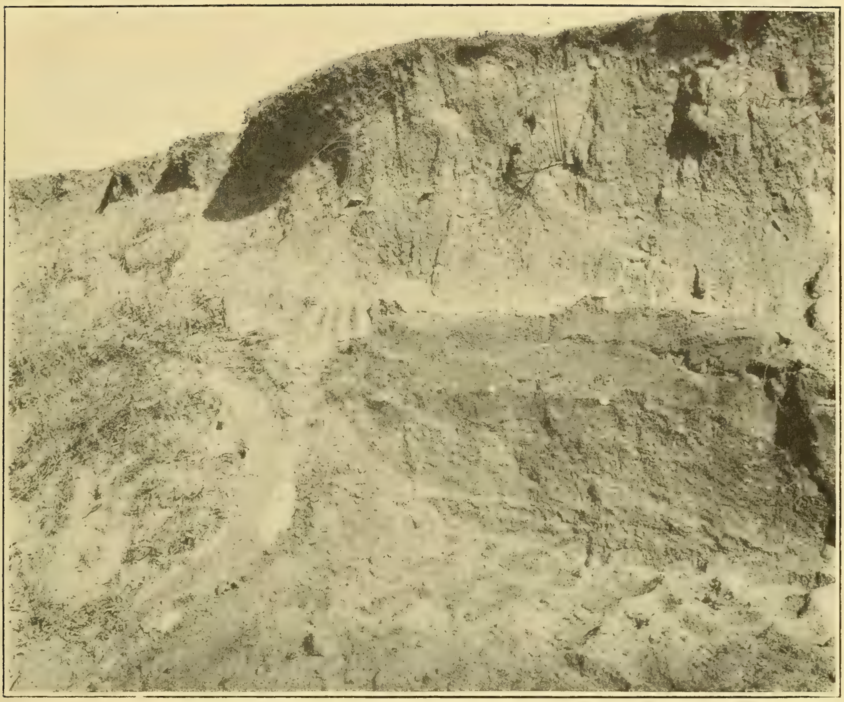

FIGURE 1.—VIEW IN AN ABANDONED GRAVEL PIT NEAR DORIS, BUCHANAN COUNTY, IOWA

Below the markers is a thick bed of Buchanan gravels, only partially exposed. When the pit was worked the gravel was taken out down to the blue Kansan till. Above the markers is a bed of typical Iowan, 8 to 10 feet thick. The Iowan becomes thinner toward the left and thicker toward the right.

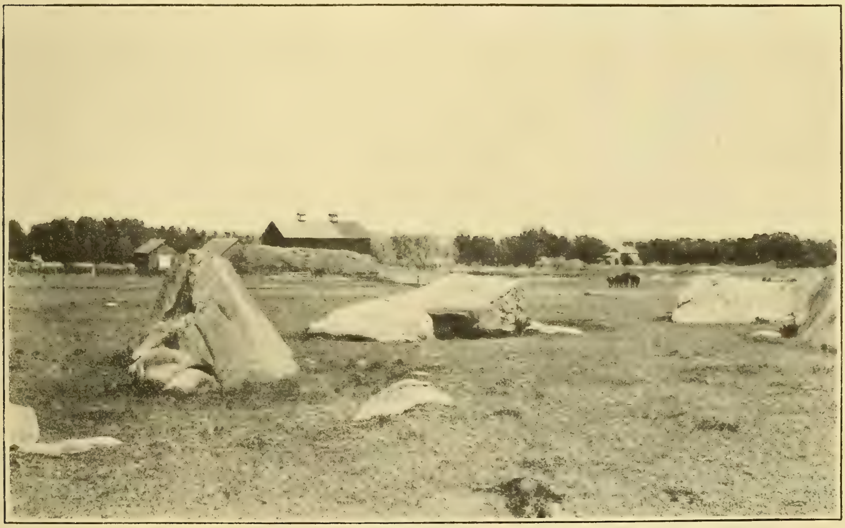

FIGURE 2.—THE YOUNG, UNERODED IOWAN DRIFT PLAIN, WITH CHARACTERISTIC GRANITE BOULDERS. VIEW EAST OF WINTHROP, IOWA

GLACIAL PHENOMENA IN BUCHANAN COUNTY, IOWA

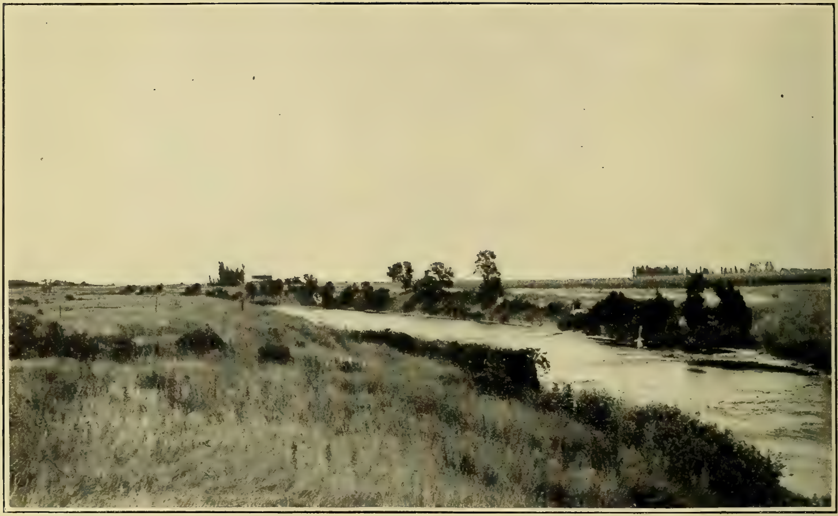

FIGURE 1.—SHALLOW, NARROW TRENCH OF THE SHELL ROCK RIVER, IN CERRO GORDO COUNTY, IOWA

Showing a characteristic young Iowan stream

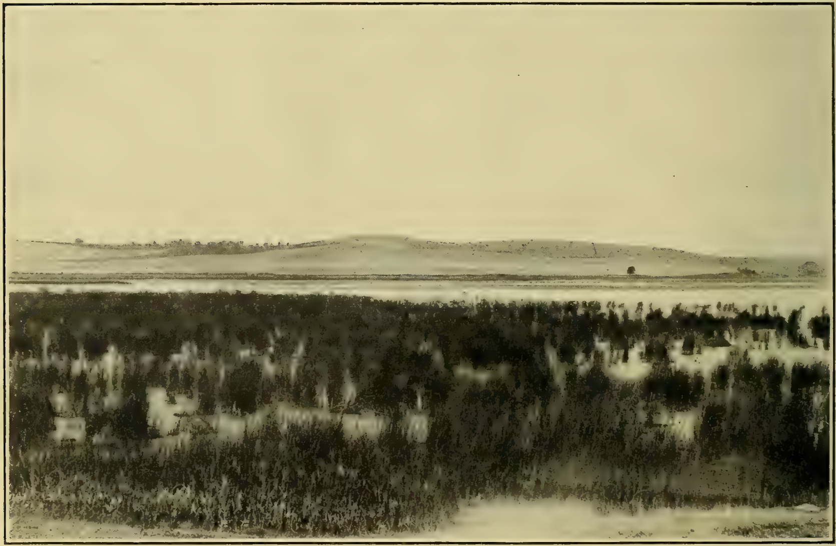

FIGURE 2.—ELBOW LAKE AND PART OF THE MORAINE SOUTH OF RUTHVEN, IOWA

Illustrating some characteristic topographic features of the very young Wisconsin drift.

GLACIAL PHENOMENA IN CERRO GORDO AND PALO ALTO COUNTIES, IOWA in some localities, lie on the surface or are but partly embedded, and they contribute striking and diagnostic features to the Iowan landscapes (plate 4, figure 2). Their prominence above the surface in a region which has suffered no erosion has led at least one geologist to conclude that they represent superglacial material carried by the Iowan ice and gently lowered on the surface as the glacier melted. Setting aside the obvious difficulties in the way of accounting for superglacial drift on the surface of a continental ice-cap traversing a region of low relief, there is evidence in the large proportion of planed specimens, great and small, that the Iowan boulders were transported beneath the ice. To meet a demand for suitable blocks for bridge piers and heavy foundations, many of the larger boulders were actually quarried in Buchanan, Black Hawk, and other counties; and in a majority of cases, when the last pieces were lifted out of the shallow pits in which the granites lay, the lower surface showed a face, flattened and scored, many feet in diameter. These boulders were probably embedded completely in the lower surface of the ice; the ground moraine otherwise was very thin; the granites now stand out conspicuously above the surface, because the subglacial drift, as a whole, was insufficient in amount to conceal them.

DRAINAGE COURSES IN THE IOWAN

A discussion of the general surface features of the Iowan should include some reference to the drainage courses. These add some special characteristics to the young drift plain. In many instances, owing to the meagerness of the drift, the streams recovered their old, pre-Iowan valleys after the disappearance of the ice; but some were obliged to seek new courses across the drift plain, and these now flow in shallow trenches almost at the level of the cultivated fields (plate 5, figure 1). There are here no valleys in any proper sense, no river bluffs, no floodplains; the Iowan streams are young; they have barely commenced to cut their valleys; they have very few tributaries; the lateral drainage is effected by flow along the broad sags of the original surface, instead of being limited to definitely cut channels; over extensive areas the drainage is sluggish and imperfect.

AGE OF IOWAN COMPARED WITH KANSAN

After this review of its general characteristics we may compare the Iowan drift with the Kansan, giving especial attention to criteria indicative of age. The differences seem almost immeasurably great. With the exceptions already noted—namely, low-lying areas or the axes of very broad divides—the whole of the original Kansan plain has been completely carved and sculptured by flowing water and a miniature type of mature erosional topography has been developed. There are no undrained upland areas; the rain-cut trenches have invaded every part of the original plateau. In parts of southwestern Iowa the rivers—for example, the Nodaway, at Hepburn, in Page county—have eroded valleys in the Kansan drift 200 feet in depth and 3 or 4 miles in width. At Iowa City the Iowa river has made a valley 80 feet in depth since the Kansan, and half of this depth has been cut in Devonian limestone. All the streams of the Kansan area and practically all parts of the Kansan surface tell the same consistent story; all record a long period of active erosion. Along the Iowan-Kansan border there are many points where the differences are strikingly brought out. On one side of a fairly definite line the topography is water-carved; on the other side it is ice-moulded; on one side a series of rounded, billowy, loess-covered ridges fitting into a dendritic system of broadly open, erosion-cut ravines; on the other a great boulder-dotted plain, untouched by erosion, over extensive areas as level as a floor. The amount of erosion over the general surface of the Kansan is many times as great as that over the general surface of the Iowan. If differences in the amount of erosion may be taken as a fair measure of the differences in the age of two drift sheets, then the Kansan is certainly a hundred times as old as the Iowan. If the two drifts be compared with reference to the magnitude of the changes brought about by weathering, a similar conclusion is reached. The great thickness of the altered and oxidized zone in the Kansan was noted in making comparisons with the Illinoian, and reference has also been made to the inappreciable amount of weathering in the Iowan. To say that weathering in one case is one hundred times as great as in the other is to make a very conservative estimate. If weathering is a measure of age, we may repeat the statement already made, that the Kansan is certainly one hundred times as old as the Iowan.

Fourth interglacial Interval, the Peorian

The Peorian interglacial interval, which followed the Iowan ice stage, was very short, and at its close a fifth ice-sheet, coming from the Kewatin center, flowed into Iowa and distributed the body of till called the Wisconsin. As in the case of the Iowan, it was only a terminal lobe of the Wisconsin that crossed the Iowa-Minnesota line. In the main, the Wisconsin lobe lies to the west of the Iowan; it overlaps the Iowan for some distance along its eastern edge; in general it overlies loess-covered Kansan. The southern extremity of the Wisconsin drift lobe is at Des Moines, and within the city limits excavations for various purposes have given sections showing (1) profoundly altered, oxidized and weather-stained Kansan drift; (2) fossiliferous loess containing Succinea, Pupa, and other terrestrial mollusks belonging to species still living in the locality, and (3) Wisconsin drift, with boulders 3 to 4 feet in diameter. Many of the exposures were made in grading streets or excavating for foundations, but a section that will not be concealed for some time may be studied at the tile works in East Des Moines. Still better sections were seen a few years ago in the fresh cuts made by the Great Western railway in the western edge of the Wisconsin lobe, near Carroll. These were studied in detail by Shimek, and showed (1) typical Kansan oxidized and otherwise weathered for some feet below the original surface; (2) an old blue, fossiliferous loess, with a weather-stained band at the top and many ferruginous cylindrical concretions throughout its whole thickness; (3) a much younger, unaltered, yellow post-Iowan loess, and (4) Wisconsin drift. There are no known sections showing direct contact of the Wisconsin with the Iowan, but the yellow loess on which the Wisconsin rests at Carroll and at so many other points in Illinois and Iowa has, on good grounds, been correlated with events which followed the disappearance of the Iowan ice. The loess of certain parts of the Mississippi valley is a deposit belonging to the Peorian interglacial interval, and the Wisconsin lies on top of it. The changes whch took place in the Iowan drift during this entire interval are too small for numerical or relative expression. The interval, compared with the Yarmouth or the Sangamon, was very short. The Iowan is probably not more than twice as old as the Wisconsin.

Wisconsin Drift

CHARACTERISTICS OF THE WISCONSIN COMPARED WITH THOSE OF THE IOWAN

The Wisconsin drift sheet is something very distinct from the Iowan. It differs in composition, being excessively calcareous, while the amount of lime carbonate in the Iowan, in any form, is very small. The calcareous constituent of the Wisconsin drift takes the form of fine limestone flour mixed with the clay, together with great numbers of limestone pebbles. It differs also in color; the color is a lighter yellow. Furthermore, the Wisconsin differs from the Iowan in habit. The Iowan drift is thin and meager, and fails completely over large areas toward the margin of the lobe. From areas even in the interior of the lobe it may be absent. The Wisconsin drift is more abundant; it completely disguises the pre-Wisconsin topography; in most cases it becomes thicker toward the margin. The ice of this stage seems to have been heavier and more energetic; it scoured down to bedrock in the limestone areas north of

Iowa; it carried quite a load out to its margin; it constructed morainic knobs and ridges, such as Pilot Knob and its associates in Hancock county, 100 feet in height in some cases, with material actually thrust out and heaped up around the edge of the ice. Besides being a moraine-forming ice-sheet, the Wisconsin is responsible for the largest amount of Pleistocene gravels to be found in the state. The streams and surface sheets of water were large in volume and were loaded to their full capacity. Whole townships are covered with coarse outwash gravels in continuous sheets, and gravel trains occur along all the drainage courses leading out from the edge of the Wisconsin drift. In a wide belt along the western border of the lobe, in Osceola, Dickinson, Palo Alto, and Clay counties, the surface is marked by hundreds of knobs and ridges of gravel having the form of kames or eskers. This feature may be said to culminate in Ocheyedan mound in Osceola county, a noted and conspicuous gravel kame so prominent that it commands attention from every part of the area surrounding it within a radius of 25 miles. The many scores of other gravel ridges along this western border of the Wisconsin are only less interesting than Ocheyedan mound because they are smaller in size.

In marked contrast with all this evidence of kame-forming and general gravel-depositing habit of the Wisconsin are the meager indications of outwash from the Iowan. The Iowan ice was certainly very thin and inefficient near its margin, and most of the water produced by melting may have been disposed of by evaporation. Along some of the streams which drain the Iowan lobe and flow beyond its margin there are a few sand terraces, usually small; but on the upper Iowa river, near Decorah, there are extensive deposits of fresh sand which have been correlated with the melting of the Iowan ice. Down in the valley of the Iowa river at Iowa City, in the relatively young gorge which has been excavated since the Kansan, there are sand terraces of Iowan age beneath river silt and ordinary loess. On the whole, however, the evidence of floods of any force or volume, flowing from the wasting Iowan ice, is almost zero. All the known deposits referable to the melting phase of the Iowan are sands; never do they assume the character of gravels such as would require the agency of energetic currents.

Comparing the surface features in the larger way, the differences in these two drift sheets in Iowa are still obvious and decisive. Apart from the gravel kames and morainic knobs already noted, there are differences due to the larger quantity of material carried to the outmost limit of its territory by the Wisconsin ice. Owing to greater thickness of the glacial deposit, there are, as a rule, no signs of the old Kansan topography expressing itself through the younger drift mantle. The surface records simply the eccentricities of ice deposition, and nothing else. There are many square miles of level plain without signs of knobs or ridges, but with thousands of acres of shallow, reedy marshes and ten of thousands of acres of flat meadow land, above which rise, with scarcely perceptible slope, to a height of very few feet, the low swells which may be cultivated under natural drainage conditions. Efforts at reclamation by means of artificial ditches have been made in places with greater or less success; but so broad are the level plains, so slight the grade, and so far away the possible outlet for the ditch waters that the problem of drainage is a serious and difficult one. Lakes ponded in depressions among the morainic knobs (plate 5, figure 2) and saucer-shaped kettle-holes, varying from a rod or two to half a mile in diameter, distributed over the flatter parts of the lobe, are other characteristic surface features of the Wisconsin drift.

There seem to be two phases of the Wisconsin represented in Iowa, and these may possibly correspond to the Shelbyville and Bloomington sheets differentiated in Illinois by Leverett. The well defined moraine passing southward through Dickinson, Clay, Buena Vista, Sac, and Carroll counties marks the western edge of the ice during the latest phase of the Wisconsin. But outside the moraine west of Ruthven, in Osceola, O'Brien, Clay, and some of the adjacent counties, there is an area occupied by drift having all the characteristics of the Wisconsin, except that there are few morainal features; and marshes and kettles are much less numerous than in the inter-morainal portion of the lobe. This area belongs to the Wisconsin; the drift may represent the earlier Wisconsin; but it is quite possible that the position of the moraine may indicate simply a recession and halt of the ice, and that the Wisconsin drift in Iowa is, after all, but a single sheet. But whether there be one or two phases of the Wisconsin, this last of our known drift sheets presents characteristics of extreme youth.

THE WISCONSIN COMPARED WITH THE KANSAN

As you know, the old sub-Aftonian or pre-Kansan drift is exposed only in stream valleys or in artificial excavations. It gives character to the surface of no large area as do the several till sheets which followed it. It was everywhere covered by the widespread mantle of Kansan drift, and erosion and weathering, so far as it was concerned, came to an end at the time of the second ice invasion. In the case of each of the other drifts, there are extensive areas over which they have been exposed to the action of the atmosphere and drainage waters ever since they were deposited;

and it is to this fact that we owe the possibility of making estimates as to relative age. The oldest glacial deposit in which the accumulating effects of continuous time is recorded is the Kansan; the youngest is the Wisconsin; and between the two the differences in age seem almost immeasurable. Comparing the weathering and erosion in the central, intermorainic part of the Wisconsin with the corresponding evidences of change in the Kansan, the differences must be expressed by a number greater than one hundred. It cannot be affirmed that changes have progressed at a uniform rate in each bed of drift or during all parts of Pleistocene time; but, making every possible allowance, there is no escape from the conclusion that the Pleistocene was a long, long period, compared with which the recent period, or post-Glacial time, would have to be represented by a very small fraction. The Yarmouth, or even the Sangamon interval, was long as compared with the post-Wisconsin.

CONCLUSION

The facts presented in this address show that the history of the remarkable period we call the Pleistocene was vastly more complex than was suspected by any one twenty years ago; but, complicated as this history now seems, it is possible that we have just made a beginning in recovering the leaves of the fuller and larger history which will include Pleistocene details at present unknown and undreamed—details which will clearly illuminate every successive step in the evolution of the world as we know it today from that which existed at the close of the Tertiary. In the presidential address on Pleistocene history which will be delivered before this Society twenty years hence there will probably be descriptions of drift sheets—now unknown because completely buried under younger deposits—dividing the long Yarmouth and Sangamon intervals; there will be more interglacial phases, fuller discussions of interglacial faunas and floras, more significant details of every sort and kind. Some who are here today may have the privilege of listening to that address and of joining with the younger men of the time in expressing surprise at the meagerness of the knowledge of Pleistocene history possessed by geologists during the first decade of the twentieth century.

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FIRST CALCAREOUS FOSSILS AND THE EVOLUTION OF THE LIMESTONES[1]

BY REGINALD A. DALY

(Read by title before the Society December 29, 1908)

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INTRODUCTION

It may be assumed that the average water of the ocean has not been of the same composition in any two of the geological periods. The ocean has had a chemical evolution. Though the amount of water may have remained tolerably constant from the pre-Cambrian time to the present, it seems certain that the amount and character of the mineral matter dissolved in the ocean must always have been changing. The inflow of river-borne salts has varied in rate according to the area of the lands and according to the kinds of rocks exposed to subaerial erosion during the different periods. On the other hand, there are reasons for believing that the precipitation of salts from the sea-water (including biochemical precipitation) has occurred at variable rates. The composition of the existing average sea-water may conceivably be dependent on four other factors: *a,* the primitive condition of the ocean before the régime of the rivers was established; *b,* the direct solution of submarine rock by sea-water; *c,* the emission of acids and soluble salts at volcanic vents; and,

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[1] Manuscript received by the Secretary of the Society January 8, 1909.

d, the inflow of salts-laden "juvenile" waters in the form of submarine springs which are fed from the earth's interior.

In tracing the history of the ocean water, the variations in the supply of river-borne salts and in the rate of chemical precipitation of salts are the factors which seem to permit of at least a crude analysis. They are likewise the factors most important in their bearing on the origin of the calcareous fossils in the rocks and on the origin of the limestones and dolomites. These two problems have been attacked again and again, but rarely, in either case, on the basis of a variable content of mineral matter in the oceanic solution.

The writer has discussed at some length the hypothesis that the secretion of calcareous hard parts by marine organisms was first made possible as a result of the increase of the land areas during the post-Huronian orogenic revolution.[2] That enlargement of the continents caused a great increase in the annual supply of river-borne salts to the ocean. The supply was specially enlarged by the upturning and erosion of the thick limestones which had been deposited on the sea-floor of earlier pre-Cambrian time. These limestones are regarded, on the hypothesis, as precipitates of calcium and magnesium carbonates, thrown down when the river-borne salts diffused to the ancient sea-bottom. The chief reagent for the precipitation is considered to be the ammonium carbonate generated by the decay of animal matter.* It is further postulated that in pre-Cambrian time the active scavenging system had not yet been evolved; that therefore the amount of decaying animal matter on the pre-Cambrian sea-floor was vastly greater than the amount now allowed to decay on the bottom of the ocean. The smallness of the annual supply of river-borne calcium salts, coupled with this specially rapid precipitation of calcium carbonate, is supposed to have kept the pre-Huronian ocean nearly limeless; only the minute traces of calcium salts contained in the river waters as they diffused to the sea-bottom would be found in the ocean of that time. At the bottom the water would be practically limeless.

The nearly limeless condition of the surface water was changed by the extensive orogenic and epeirogenic movements of post-Huronian time. In the Cambrian period the animal species had begun to armor themselves with the new material, henceforth present in the sea-water in sufficient amount. The primitive chitinous shell now became strengthened with phosphate and carbonate of calcium, and in the Ordovician many species had adopted the armor or skeleton of pure calcium carbonate.

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[2] American Journal of Science, vol. xxiii, 1907, p. 93.

* The reaction is the same as that occurring within the *living* mollusc as it "secretes" its shell. See R. Irvine and G. S. Woodhead, Proceedings Royal Society of Edinburgh, vol. 16, 1889, p. 352.

The Ordovician and Silurian rocks were therefore the first to be charged with calcium carbonate shells and skeletons in large numbers.

The hypothesis further states that not only a large part, if not all, of the pre-Cambrian limestones and dolomites, but, as well, the limestones and dolomites of the early Paleozoic formations, are chemical precipitates thrown down by ammonium carbonate. This precipitation grew slower in proportion to the development of the fishes and other efficient bottom scavengers. When the scavenging system became well established calcium salts could, for the first time, accumulate in the ocean water in excess of the needs of lime-secreting organisms. Thereafter the marine limestones have been largely formed from the débris of the hard parts of animals and plants.

The original paper contains a discussion of various tests of the suggested hypothesis. These included, first, the witness of laboratory experiments; secondly, the testimony of the Black sea—a basin where modern limestone is being deposited by the organic alkali because of the lack of a scavenging system over most of the basin-floor; and, thirdly, the lithological evidence of pre-Cambrian sedimentary deposits. The present paper is intended to suggest the value of additional evidence based on the chemistry of the rivers draining pre-Cambrian terranes. In addition, the testimony of the microscope to the chemical origin of thick Cambrian and pre-Cambrian limestones is briefly outlined, and the systematic chemical variation of the limestones through geological time is quantitatively discussed.

THE TERRANE AND THE RIVER SOLUTE

The influence of the kind of rock traversed by a river on the chemical composition of that river is clearly illustrated by Hanamann's careful investigation of the Bohemian rivers.[3] His results are in part summarized in the following table (I), in which the content of calcium and the content of magnesium in streams issuing from different rock formations are given:

TABLE I.

Waters from—	Calcium in parts per million.	Magnesium in parts per million.	Ratio of calcium to magnesium.
Granite	7.73	2.33	3.32 : 1
Phyllite	5.72	2.41	2.37 : 1
Mica-schist	9.33	3.76	2.48 : 1
Basalt	68.84	19.76	3.49 : 1
Cretaceous (partly limestone)	133.38	31.36	4.25 : 1

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[3] J. Hanamann: Archiv Natur. Landesdurchforschung Böhmen, vol. 9, no. 4, 1894; vol. 10, no. 5, 1898—quoted in F. W. Clarke's "Data of Geochemistry," Bulletin no. 330, U. S. Geological Survey, 1908, p. 79. Cf. also A. L. Ewing, American Journal of Science, series iii, vol. 29, 1885, p. 29.

Since these various waters were working under like climatic (solutional) conditions, the control of the terrane over the amounts of dissolved calcium and magnesium is manifest.

After a detailed study of the question, Dubois estimates that on an average, *ceteris paribus*, rivers flowing entirely over silicate rocks carry only one-tenth as much calcium carbonate as rivers flowing entirely over limestone, and remarks that even this fraction is almost certainly too large. According to his estimates, only one-thirtieth of the calcium carbonate annually entering the sea has been newly formed through the decomposition of silicates. The rest is derived from the direct solution of limestone. He has further concluded that in early Archean time the world's river system probably carried each year not more than one-eighth as much carbonate to the ocean as the existing river system carries.[4]

EFFECTS OF THE POST-HURONIAN REVOLUTION

From the lithological nature of the Huronian and pre-Huronian formations as well as from other general considerations, we may believe that the Huronian and pre-Huronian lands were chiefly composed of acid, granitic and schistose rocks. The post-Huronian orogenic revolution lifted very thick and extensive (Grenville and other) limestones, as well as huge masses of basaltic rocks above baselevel.[5] From the quantitative studies of Hanamann and Dubois we may believe with equal readiness that the annual supply of calcium to the ocean after the revolution was from two to five or more times that characteristic of Huronian and pre-Huronian time.

The revolution must have had another important effect—in decreasing the sea-bottom area on which the precipitation of calcium carbonate took place. The researches of the "Challenger" chemists show that at depths greater than 3,000 fathoms, little or no solid calcium carbonate can remain on the sea-floor. In fact, the tendency to the complete solution of this salt is strong at all depths greater than 2,500, if not 2,000 fathoms. This means that the permanent removal of calcium carbonate from the present oceanic solution through the decay of animal carcasses at the bottom seems to be possible only in about one-half of the existing ocean basin—say 70,000,000 square miles. This area is partly neritic (depths less than 200 fathoms) and partly bathyal (depths between 200 fathoms and 2,000 fathoms). On account of the higher temperatures and lower bottom pressures (pressure increasing the solubility of the carbonate) of the shallower water, we should expect the rate of chemical precipitation of calcium carbonate at the bottom to be concentrated in the neritic (epicontinental) and shallower bathyal regions, a total area of, say, 35,000,000 square miles.

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[4] E. Dubois: Proceedings of the Section of Sciences, Kon. Akad. van Wetenschappen, Amsterdam, vol. 3, pp. 119-126.

[5] Cf. F. D. Adams: Journal of Geology, vol. 16, 1908, p. 617.

Let us assume that previous to the post-Huronian orogenic revolution the whole area of the lands was 20,000,000 square miles, or about 20/55 of the present area. On the view that the ocean has had a nearly constant volume from Huronian times to the present, it follows that the Huronian sea was largely epicontinental for an area of more than 35,000,000 square miles; so that the area of rapid chemical precipitation of calcium carbonate was about twice as great as the possible present area. Let us also assume that the post-Huronian revolution increased the land area to 55,000,000 square miles, which is roughly the present area of the lands.[6]

The annual rate of the supply of calcium to the ocean was, on these assumptions, increased from (55/20 × 2 =) 5.5 to (55/20 × 5 + =) 14+ times by the post-Huronian crustal movements. But the sea-bottom area over which the chemical precipitation of calcium carbonate was compelled was halved by those movements. Thus the post-Huronian conditions favoring the possibility that a part of the river-borne calcium could remain in solution in the ocean were from (5.5 × 2 =) 11 to (14 × 2 =), 28 or more times more effective than the pre-Huronian conditions.

Although little stress can be laid on any particular figure embodied in the foregoing conclusions, this rough analysis serves to illustrate the strength of the probability that the prodigious crustal movements of the post-Huronian and pre-Cambrian interval made a comparatively rapid and quite drastic change in the chemical condition of the ocean.

ANALYSES OF THE OTTAWA RIVER

The view that the supply of calcium to the ocean reached a maximum rate in post-Huronian and pre-Cambrian time is based on some speculation. Apparently more certain are the grounds for believing that the late pre-Cambrian ocean could have received an annual calcium supply which was only a small fraction of the present annual supply. The belief may be founded on a comparison between the analyses of rivers now draining large pre-Cambrian areas with the analyses of rivers draining average terranes of the present continents.

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[6] Joly's well known estimate of the age of the ocean as about 90,000,000 years seems much too low for the needs of the geologists. His view that the sodium borne into the ocean by the rivers during past time is nearly all represented in the present sea-water is apparently one of the soundest in dynamic geology. The chief source of doubt as to the validity of his method of calculation consists in the obvious fact that it is not yet possible to secure even an approximate idea as to the secular variation of the land area in size. The age of the ocean would be greatly increased if account be taken of a relatively small land area throughout much of pre-Cambrian time. To the present writer Joly's estimate is of value in suggesting that the pre-Huronian land area was in reality small. J. Joly, Scientific Transactions, Royal Dublin Society, vol. 7, 1899, p. 23.

Few rivers are more typical of the former class than the Ottawa above Ottawa city. Its thousands of miles of trunk and branch channels are sunk in the largest pre-Cambrian area of the world, and it happens that most or all of the recognized rock types of the pre-Cambrian formations are liberally represented in its drainage basin. Only very small and practically negligible masses of younger rocks occur in the basin above the city of Ottawa.

At the request of the writer, Mr F. T. Shutt, chemist to the Dominion Experimental Farms, has very kindly made two analyses of the Ottawa water, taken at the Chaudiere falls, which face the city. The first sample was collected on March 12, 1907, at a time when the river was still ice-covered and reported to be at the lowest stage known in fifty years. The second sample was collected on July 16, 1907, during the summer high-water period. Its analysis is more complete than that of the first sample. The two gave results shown in columns 1 and 2 of table II.

TABLE II.

	1. Low water.	2. High water.
	Parts per million.	*Parts per million.*
Total solids at 98–100° centigrade	54.66	46.07
Loss on ignition	24.03	15.74
Solids after ignition	30.63	30.33
SiO_2	6.52	7.06
Al_2O_3	.38	.52
Fe_2O_3	.34	.70
MgO	3.87	2.77
CaO	12.57	8.18
Na_2O	not det.	2.14
K_2O	not det.	.67
SO_3	3.70	2.51
Mn_3O_4	not det.	.86
P_2O_5	not det.	.43
Cl	not det.	.50

Five sanitary analyses of the Ottawa river water have been made by Mr Shutt. The samples were taken on the following dates: December 22, 1887; October 18, 1898; December 7, 1898; May 8, 1899, and August 22, 1905. These analyses gave, respectively, total solids at 53.0, 55.6, 42.4, 48.8, 62.4 parts per million, and solids after ignition (December 22, 1887, not determined), 34.0, 28.0, 22.8, 36.4 parts per million. The figures average 52.4 parts per million for total solids and 30.3 parts per million for solids after ignition. It will be seen that the variation in each of the two quantities from year to year and from season to season is relatively small; hence we may conclude that the two 1907 analyses fairly represent the average nature of the Ottawa river water in modern times.

The content of calcium and magnesium of the two stages of the river, and their mean have been calculated to parts per million and the results entered in table III, which also gives, for purposes of comparison, the calcium content of other rivers, as well as of the Ottawa river at Sainte Anne rapids below the solid block of Paleozoic limestones lying between Ottawa and Montreal. The references for the original publications of these latter analyses may be found on page 60 of Bulletin number 330 of the United States Geological Survey.

TABLE III.

River.	Terrane.	Calcium.	Magnesium.	Ratio of Ca to Mg.
		Parts per million.	*Parts per million.*	
Ottawa—				
a. Low water	Late pre-Cambrian	8.98	2.35	3.50 : 1
b. High water	ditto	5.84	1.67	3.82 : 1
c. Mean of *a* and *b*		7.41	2.01	3.69 : 1
d. Sainte Anne	Late pre-Cambrian and early Paleozoic.	9.92	2.02	4.91 : 1
Average of four Swedish rivers and Ottawa and Pigeon rivers.	Late pre-Cambrian	6.88	1.52	4.52 : 1
Saint Lawrence at Ogdensburg—average of 6 monthly analyses.	Late pre-Cambrian and Paleozoic.	32.05	7.21	4.44 : 1
Mississippi—				
a. At Minneapolis—average of 23 analyses.	Late pre-Cambrian and early Paleozoic.	41.18	15.34	2.69 : 1
b. Memphis—analyses of 17 composites.	Late pre-Cambrian and Paleozoic chiefly.	34.38	13.75	2.50 : 1
c. New Orleans—average of 52 composites.	Nearly average continental mass of present time.	33.90	8.65	3.92 : 1
Danube—average of 23 analyses.		43.89	9.94	4.42 : 1
Rhone—average of 5 analyses.		44.91	6.22	7.22 : 1
Seine		73.99	1.60	46.24 : 1
Average of 19 rivers (Murray).[7]	ditto	33.85	7.75	4.37 : 1
Average of 44 rivers	ditto	37.77	9.03	4.18 : 1

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[7] Sir John Murray: Scottish Geographical Magazine, vol. 3, 1887, p. 65.

Comparison of the Ottawa and other Rivers

The Ottawa carries past Ottawa city only 23 per cent as much calcium per volume as the Saint Lawrence river carries past Ogdensburg, and less than 20 per cent as much calcium per volume as the Mississippi carries past Minneapolis. About one-third of the Saint Lawrence basin is occupied by the Great lakes, in which area probably very little solution of calcium salts is taking place. Another large part of the basin is occupied by the pre-Cambrian terranes where highly calcareous rocks are relatively rare. The content of this river is therefore less than it would be if the river basin were all occupied by the average rocks of the whole continental area of the earth. The comparison of these three rivers is specially instructive, since they are all working under essentially similar climatic conditions, with nearly the same ratio of rainfall to run-off. From the comparison it seems probable that, if the continents were all of their present size and composed of rocks typical of the lands during the late pre-Cambrian, the rivers would deliver to the sea annually not more than one-fifth as much calcium as is carried by the existing rivers of the continents.

This conclusion becomes more convincing when the Ottawa water is compared with the other rivers noted in table III.

In Clarke's admirable cimpilation of river analyses, those referring to rivers which drain pre-Cambrian terranes throughout their respective basins are five in number, including the Pigeon river of Minnesota and four rivers in Sweden. The average content of calcium (and of magnesium) in these rivers, together with the Ottawa at Ottawa city, is stated in the table. It will be seen that the proportion of calcium is very close to that in the Ottawa alone. We have, therefore, corroboration for the view that the Ottawa is a good world type of rivers draining late pre-Cambrian terranes.

On the other hand, the Mississippi at New Orleans must be regarded as one of the best types of rivers draining the average terranes of the present continents. From Murray's average of nineteen rivers the present writer has calculated the proportions of calcium (and magnesium) and has also (using Clarke's compilation) calculated the contents of these elements in forty-four of the largest rivers of the globe. In this second computation the individual analyses were roughly weighted according to the areas of the respective river basins. The result is believed to give a truer idea of the average content of calcium in the world's rivers than does Murray's estimate.

The results seem to show that the average world river, working on the average terrane and under average climatic conditions, carries about the same proportion of dissolved calcium as the average water of the Saint Lawrence at Ogdensburg and the Mississippi above Minneapolis. The table indicates that the influence of the terrane is dominant and the influence of climate subordinate, in their respective controls over the content of calcium.

The Mississippi above Memphis drains rock formations which together make fairly good equivalents of the average Mesozoic and Cenozoic land areas. So far as the influence of the average world terranes is concerned, the Mesozoic and Cenozoic rivers were enriched in calcium about as much as the existing world rivers. The early Paleozoic rivers were, on the average, probably not much richer in calcium than the late pre-Cambrian rivers. The control of the Paleozoic terranes on the calcium content of the Ottawa itself is shown by the contrast between the Ottawa city analyses and that at Sainte Anne near Montreal. Even a few hundred square miles of upper Cambrian and Ordovician rocks (largely limestones) below Ottawa city makes the calcium content materially rise.

CHEMICAL CONTRAST OF PRE-CAMBRIAN AND LATER RIVER SYSTEMS

In spite of the complexity of the whole problem, we may fairly conclude that if, in the late pre-Cambrian time, the land areas were of their present size, the ocean then received annually only a small proportion—probably less than one-fifth—of the calcium supplied each year by the present rivers. A contrast of the same order must have existed between the calcium content of the late pre-Cambrian rivers and the rivers characterizing most of Mesozoic and Cenozoic time.

If the late pre-Cambrian lands had a total area but one-half as great as the present total land area, the rivers may have carried annually to the sea less than 10 per cent of the amount of calcium now carried to the sea by the world's rivers.

This estimate obviously involves the assumption that the pre-Cambrian rate of chemical denudation was no more rapid than the present rate. Since the rate is controlled (apart from the influence of the terrane) principally by the abundance of the organic acids attacking the bedrock, we may well suppose that the well vegetated Ottawa river basin is witnessing solution at as rapid a rate as in late pre-Cambrian time. It might be considered that a tropical temperature during the pre-Cambrian would have caused specially rapid solution of the rocks at that time. This view is, however, hardly supported by an inspection of the data relating to existing tropical and extra-tropical rivers. Furthermore, the recent glaciation of the Ottawa basin has caused the removal of secularly weathered rock, so that the formations now exposed to erosion contain nearly their original amount of soluble matter. For this reason the calcium content of the existing river may be near its possible maximum for a region of average rainfall.

Without further entering upon this confessedly obscure subject, we may retain the foregoing estimate as indicating the order of magnitude in the contrast between the late pre-Cambrian and present supply of calcium to the ocean through weathering and river inflow.

VARIATIONS IN THE CALCIUM SUPPLY DURING AND AFTER THE PRE-CAMBRIAN

Before the post-Huronian revolution the supply of river-borne calcium to the ocean was almost certainly less than one-fifth as rapid as it is today, and it may have been less than one-twentieth as rapid, while the amount of animal matter completely decaying each year on the sea-floor, and therewith the likelihood of the precipitation of calcium salts, may have been, respectively, thousands of times greater than they are now.

Immediately after the post-Huronian revolution and during the immensely long period of baseleveling which followed it, the annual supply of calcium to the ocean may have approached rivalry with the present annual supply. The supply doubtless diminished somewhat as more and more of the Huronian and pre-Huronian limestone and basaltic areas were lessened by erosion and as the Laurentian granite batholiths were uncovered and exposed to solution; but this change must have been very slow, and it did not annul the critical effect of continental enlargement. During the long erosion cycle the ocean was, for the first time, specially enriched in river-borne calcium salts.

THE FIRST CALCAREOUS FOSSILS

This special influx of calcium salts may be conceived as keeping the surface layers of the sea-water sufficiently supplied with calcium for the needs of lime-secreting organisms, while the bottom layers lost their calcium content by precipitation of the carbonate of calcium. Such contrast of surface and bottom water would be due to the slowness of diffusion through a body of liquid so great as the ocean. Under the conceived conditions the most favorable places for the invention of calcareous hard parts would be, possibly, localized areas, such as the open sea opposite the greater river deltas, or such as the epicontinental seas more or less isolated during the orogenic revolution. The slow spread of the scavenging system may already have had some effect in the late pre-Cambrian, thus increasing the chances that some calcium could remain in the oceanic solution.

Since lower Cambrian time the continents have in part undergone submergence and emergence, but they have doubtless never resumed their small total area characteristic of the pre-Huronian period. In any case we have obvious proofs that the ocean has, since the Cambrian, contained enough calcium for the needs of lime-secreting organisms, and the natural explanation is to be found in river inflow.

ORIGIN OF THE PRE-CAMBRIAN AND EARLY PALEOZOIC LIMESTONES AND DOLOMITES

The hypothesis that the pre-Cambrian sea was nearly limeless involves the corollary that magnesium as well as calcium must have been precipitated from the sea-water. The precipitated salt may have been the hydrous carbonate of magnesium, which then united with the calcium carbonate to form dolomite; or crystals of dolomite may have grown at or near the surface of the bottom mud in much the same way as they are growing today in the buried (porous) strata of the Funafuti atoll.[8] The chemical grounds for this belief were partially discussed in the writer's first paper.[9] It was there pointed out that ammonium carbonate is, under the conditions of the open-sea floor, almost or quite powerless to precipitate magnesium carbonate from the oceanic solution unless all calcium salts have been removed from the solution. In the absence of calcium salts, magnesium can slowly but surely be precipitated by the alkali. We should therefore expect that the formation of magnesium limestones would continue in the ocean until the general scavenging system was established, thus largely inhibiting the action of the powerful organic alkali. On this view the average pre-Cambrian limestone should show a ratio of calcium to magnesium which is close to their ratio in the average pre-Cambrian river. A similar ratio should characterize those Paleozoic limestones that were formed before the establishment of the general scavenging system. After that system was established, magnesium would begin to accumulate in the ocean.

AVERAGE RATIO OF CALCIUM TO MAGNESIUM IN THE LIMESTONES OF THE DIFFERENT PERIODS

The writer has attempted to test these conclusions quantitatively. For this purpose nearly 900 analyses of types of pre-Cambrian, Paleozoic,

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[8] The atoll of Funafuti: London, 1904, pp. 392, 413, etc.
[9] American Journal of Science, vol. 23, 1907, p. 104.

Cretaceous, Tertiary, and Quaternary-Recent limestones have been calculated, so as to show the average ratio of calcium to magnesium throughout the series. The analyses were taken from the government survey reports of Canada and the United States; from Logan's "Geology of Canada"; from the state survey reports of Arkansas, Indiana, Iowa, Kentucky, Minnesota, Ohio, Pennsylvania, West Virginia, and Wisconsin; from the reports of the Ontario Bureau of Mines; from Firket's elaborate paper on the limestones of Belgium,[10] and from the list of analyses supplied for the report on the geology of the Cordillera at the forty-ninth parallel of latitude.

The selection is far from being as complete as it might be made, but it is believed that enough analyses are represented to give a fairly accurate idea of the variation of the ratio through geologic time. The number of pre-Cambrian and Cambrian limestones averaged is, in both cases, low, but includes nearly all that seemed to be available. The number of the Tertiary and later limestones averaged is again low, but the labor of searching for additional ones did not seem necessary, since it is well known that these later limestones are usually very low in magnesium. Lesley had already prepared a remarkable series of analyses (230) which was intended to afford the average ratio for the Ordovician limestones of Pennsylvania. This result could not, however, be safely used, inasmuch as the whole series refers only to some 370 feet of beds out of several thousand feet of the limestones locally developed, and at that represents only a local phase of the Ordovician.[11] It has thus seemed better to use the analyses derived from many Ordovician formations in Canada and the United States. The ratio for the pre-Cambrian may be a little too high, for the reason that thirty-three out of the sixty-one analyses selected were taken from Miller's Bureau of Mines report on the limestones of Ontario, in which there was some tendency to select limestones specially adapted to lime burning. Excluding twelve analyses of specimens from limekiln quarries in Ontario, the average ratio for the remaining pre-Cambrian rocks is 3.61 : 1.

The results of the compilation and calculation are given in table IV.

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[10] A. Firket: Annales Société Géologique de Belgique, vol. 11, 1883, p. 221.

[11] J. P. Lesley: Final Report of Pennsylvania Survey, vol. 1, 1892, p. 327.

TABLE IV.

Period.	1. Number of analyses averaged.	2. Ratio of $CaCO_3$ to $MgCO_3$.	3. Ratio of Ca to Mg.
Pre-Cambrian—			
a. From North America, except those in *b*	28	1.64 : 1	2.30 : 1
b. From Ontario (Miller)	33	4.92 : 1	6.89 : 1
c. Average of *a* and *b*	61	2.93 : 1	4.10 : 1
d. Best general average	49	2.58 : 1	3.61 : 1
Cambrian (including 17 of the Shenandoah limestone)	30	2.96 : 1	4.14 : 1
Ordovician	93	2.72 : 1	3.81 : 1
Silurian	208	2.09 : 1	2.93 : 1
All pre-Devonian	392	2.39 : 1	3.35 : 1
Devonian	106	4.49 : 1	6.29 : 1
Carboniferous	238	8.89 : 1	12.45 : 1
Cretaceous	77	40.23 : 1	56.32 : 1
Tertiary	26	37.92 : 1	53.09 : 1
Quaternary and Recent	26	25.00 : 1	35.00 : 1
Total	865		

It will be observed that the ratio of calcium to magnesium is fairly constant for all the (392) pre-Devonian analyses, in which the average is 3.35 : 1.[12] The ratio abruptly rises in the Devonian and increases rapidly in the Carboniferous. The Cretaceous shows an apparent maximum, but it is quite possible that a larger number of analyses of Tertiary and later formations would give average ratios at least as high as that of the Cretaceous.[13]

The ratio for the pre-Cambrian limestones (3.61 : 1 to 4.10 : 1), like that of all the pre-Devonian, is significantly close to the ratio of calcium to magnesium in the rivers now draining pre-Cambrian terranes, as may be seen, for example, in the Ottawa river analyses made at the capital (low-water stage, 3.82 : 1; high-water stage, 3.50 : 1; their average, 3.69 : 1). This comparison of itself suggests that during the pre-Devonian time the river-borne magnesium and calcium were wholly precipitated after diffusing to the sea-bottom. In fact, the correspondence must be regarded as giving powerful support to the hypothesis.

The abrupt change in passing from the Silurian to the Devonian may, perhaps, be referred to the development of the fishes during the early Devonian. This development doubtless began in relatively shallow water, and the flesh-eating and scavenging fishes must have aided greatly in preventing the decay of animal matter on the bottom of the extensive Devonian epicontinental seas. During the Carboniferous, and yet more wholesale Permian and post-Permian emergence, the fishes were driven out into deeper water, where they continued the gradual colonization of the entire sea-floor. So far as the fishes are concerned, that colonization may have been complete in Cretaceous time.[14] That, at any rate, it was complete probably several million years ago seems evident from the chemistry of the present ocean. According to Murray, the calcium sulphate now dissolved in the ocean could be introduced by existing rivers in about 600,000 years. Since the sulphate is being rapidly decomposed by lime-secreting organisms and converted into deposited carbonate, it is probable that much more than 600,000 years have elapsed since the bathybial fishes and other scavengers colonized the general sea-floor to depths of 2,500 fathoms. The test case of the Black sea shows that the present content of calcium sulphate in ocean water would be largely and rapidly diminished if the scavenging system were not now at work in the ocean.

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[12] On account of the difficulty of finding enough analyses stated for the rocks of the other continents, the comparison of the limestones has been largely confined to the North American formations. An incomplete, preliminary study seems, however, to show that there has been a parallel succession of chemical types among the limestones of the other continents.

[13] Cf. C. R. Van Hise: Treatise on metamorphism, 1904, p. 801, and Chamberlin and Salisbury: Geology, vol. 1, 1904, pp. 360, 404.

The ratio of calcium to magnesium in the Ottawa river, the best available type of rivers draining the average pre-Cambrian terrane, is 3.69 : 1. The ratio for the Saint Lawrence, which is not far from representing a type of the rivers which might drain the average late Paleozoic terrane, is 4.44 : 1. The ratio for the Mississippi at Memphis, similarly a fair type of river draining average Triassic, Jurassic, or Cretaceous terranes, is 2.50 : 1. The ratio for the Mississippi at New Orleans, a chemical world type for the present time, is 3.92 : 1. The ratio for forty-four existing rivers is 4.18 : 1.[15] It appears, therefore, highly probable that the ratio of calcium to magnesium for the world's entire river system has been fairly constant from the pre-Cambrian to the present. We have seen that this ratio is almost identical with that in the average pre-Devonian limestone, but is much lower than the ratio for the Devonian and post-Devonian limestones. Granting that the calcium and magnesium in sea-water have been introduced by the rivers, the sudden increase of the ratio Ca : Mg in the Devonian limestones must mean that during the Devonian the magnesium began to accumulate in the oceanic solution with special and unprecedented rapidity. On the hypothesis that the ocean was nearly limeless in pre-Cambrian time and very low in lime during early Paleozoic time, it follows that only a minute amount of magnesium could have remained in the oceanic solution during pre-Devonian time.

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[14] This speculation regarding the migration of the fishes into bathybial and abyssal depths is little better than a guess, but it is stated partly to render the hypothesis somewhat more concrete and therefore more intelligible. Meager as are the relevant facts concerning the fishes, those bearing on the Paleozoic and Mesozoic history of the bathybial and abyssal crustaceans, echinoderms, worms, and other scavenging species are almost nil. The profound mystery covering this subject does not, however, affect the general hypothesis favoring a nearly limeless ocean in pre-Cambrian time; for it is next to certain that the more efficient scavengers of the sea-floor, being all relatively high types, were not abundantly developed in Cambrian and pre-Cambrian time.

[15] So far as this ratio is concerned, a single analysis of a river may have high value in the discussion, since Dubois has shown that, no matter how much the absolute amounts of solute in a river may vary throughout the year, the proportions of the different salts remain nearly unchanged (E. Dubois, op. cit., p. 48).

Since the period of the general colonization of the sea-floor, the precipitation of magnesium carbonate direct from sea-water has been possible only under special conditions, so that the more recent time has seen the minimum formation of magnesian deposits.

SUMMARY ON THE ORIGIN OF THE PRE-DEVONIAN LIMESTONES

The close correspondence of the ratio Ca : Mg in the pre-Devonian limestones with the ratio Ca : Mg in such type rivers as the Ottawa, Saint Lawrence, and Mississippi, as well as with the average river, can hardly be accidental. The readiest explanation of this correspondence seems to be found in the view that all the pre-Devonian river-borne calcium and magnesium were precipitated on the sea-floor. The ultimate products are dolomites and magnesian limestones as well as more purely calcareous limestones. The causes for the variability of their composition are briefly discussed on pages 107-108 of the first paper. In cases where the magnesian limestones are of pre-Cambrian age they are, in general, to be regarded as precipitates on the floor of the open ocean and not as formed in closed basins subject to intense evaporation. A study of the tables of rock and river analyses has led the writer to ascribe a similar origin to the staple pre-Devonian carbonate rocks as well as to many limestones and dolomites of still later date.

TESTIMONY OF THE GRAIN OF THE PRE-ORDOVICIAN LIMESTONES

It may be added that a close study of the grain of unmetamorphosed Cambrian and pre-Cambrian carbonate rocks has convinced the writer that they are not of clastic origin nor of direct organic origin through the accumulation of shells or skeletons. More than 7,000 feet of such rocks are exposed in the Forty-ninth Parallel section of the Rocky Mountain geosynclinal prism. Type specimens of these have been examined microscopically. It was found that neither horizon nor distance from the old shorelines affects the singularly monotonous grain of the rocks.

The constituent particles are either idiomorphic and roughly rhombohedral, or anhedral and faintly interlocking. The former are everywhere of nearly uniform average diameter, ranging from .01 millimeter to .03 millimeter, with an average of about .02 millimeter. The anhedral grains range from .005 millimeter to .03 millimeter, averaging about .015 millimeter in diameter.

The same uniform grain was found in the Archean (pre-Belt terrane) dolomites (where unmetamorphosed) at the headwaters of Priest river, Idaho; in the magnesian limestones and dolomites inclosing the pre-Cambrian chitinous fossil, *Beltina danai,* in the Clarke (Livingston) range; and in the Siyeh and Sheppard siliceous limestones of northwestern Montana, which appear to be of Middle Cambrian age. In his account of the Norwegian marbles, Vogt states that the rocks of finest grain are made up of granules averaging .02 millimeter to .03 millimeter in diameter, and he distinctly states that the Norwegian dolomites are direct chemical precipitates.[16]

Again, it is important to note that the average diameters of the carbonate granules are of the same order as the average diameters of calcite and dolomite crystals, which are unquestionably due to chemical precipitation from sea-water or saline solutions at ordinary temperatures. Cullis has shown that the calcite granules deposited from sea-water in the cavities of the Funafuti corals have average diameters of from 0.02 to 0.03 millimeter; also that the dolomite crystals, which have gradually replaced the aragonite and calcite of the coral deposits, are of similar size.[17] When solutions of calcium chloride and alkaline (sodium) carbonate react at ordinary temperatures, crystals of calcium carbonate are slowly formed, which reach the same dimensions.[18] The granules constituting the "eggs" of the Belt-Cambrian oolites likewise average 0.01 millimeter to 0.02 millimeter in diameter; the eggs are clearly chemical, inorganic growths. Finally, it may be noted that a specimen of the Black sea chemically precipitated (*teste* Andrussow), calcareous mud, when microscopically examined by the writer, showed granules of similar range of magnitude.

GENERAL CONCLUSION

Notwithstanding the many uncertainties and difficulties of the case, it seems justifiable to use the Ottawa river and other analyses in an attempt to evaluate the great chemical difference between the average river water of the pre-Cambrian and that of the present time. The comparison strengthens the hypothesis that the ocean during an immense part of pre-Cambrian time was chemically unfit for the secretion of calcareous tests and skeletons. The pre-Cambrian fauna is thus regarded as largely a "jellyfish" fauna, although siliceous and chitinous fossils may be looked for in pre-Cambrian rocks.

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[16] J. H. L. Vogt: Zeitschrift für Praktische Geologie, January and February, 1898.

[17] C. G. Cullis: The atoll of Funafuti, London, 1904, p. 392; see text figures and plate F.

[18] H. B. Stocks: Quarterly Journal of the Geological Society, vol. 58, 1902, p. 54.

The ratio of calcium to magnesium in the rivers draining the pre-Cambrian terrane is almost identical with the ratio of calcium to magnesium in the average pre-Cambrian and pre-Devonian limestones. Nearly all of these limestones are credited to chemical precipitation, which steadily removed both calcium and magnesium from the pre-Cambrian ocean as fast as those elements were introduced by the rivers. The chemical reaction, which was largely or wholly responsible for the precipitation of the carbonate rocks, is also the reaction considered as responsible for the nearly limeless state of the pre-Cambrian ocean. Because the ancient dolomites and limestones were deposited, that ocean was nearly limeless; in this conception there is neither paradox nor inconsistency. The actual content of calcium in the pre-Cambrian ocean was at any moment extremely small, as the dilute solution of river-borne salts diffused to the bottom; to the pre-Cambrian organisms the ocean was practically limeless.[19]

In late pre-Cambrian time the deposition of the carbonates may have been no more than one-tenth as rapid as the deposition of the carbonates now forming, through all causes, beneath the sea. Immediately after the orogenic revolution of the somewhat earlier pre-Cambrian (post-Huronian), the deposition must have been at a maximum rate, though that rate may not have reached the one now prevailing. In any case, estimates of the earth's age, when derived from the rate and amount of past sedimentation, should take account of secular variations in the supply of river-borne salts to the ocean.

It is suggested from the facts noted in this paper that the magnesium now contained in the sea in amount greater than a mere trace began to accumulate not earlier than the Devonian period. The calcium did not begin to accumulate in similar excess until the general scavenging system was established in the "bathybial" (not "abyssal") regions of the ocean floor—perhaps as late as the Cretaceous period. When we also bear in mind that the sodium and potassium salts have been slowly accumulating from the pre-Cambrian to the present time, we are prepared to reach the rather probable conclusion that the pre-Cambrian ocean really approximated a fresh-water (though, perhaps, faintly acid) condition. The only escape from that conclusion seems to be offered in the view that a large part of the existing ocean is made of nearly pure "juvenile" water emitted from volcanic vents or from primary igneous rocks since the pre-Cambrian.

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[19] As a result of his remarkable researches on the waters found in the deeper mines of the Lake Superior region, Lane has concluded that these are "connate" waters—that is, waters which were trapped and buried in the sediments and lava-flows formed on the pre-Cambrian sea-floor (A. C. Lane's paper, read at the thirteenth annual meeting of the Lake Superior Mining Institute, June, 1908). It may be a good working hypothesis to consider the extraordinarily high content of chlorine in the many analyses as of connate origin, but the likewise abundant calcium present can be explained as due to solution along the walls of the ancient pores and fissures. To put it briefly, some elements of the mine waters *may* be connate and of marine derivation, but such original water *must* have been chemically changed by metasomatic interchange with the inclosing (always lime-bearing) rocks during the post-Cambrian period. Mine waters from pre-Cambrian terranes can not, therefore, in the writer's view, afford safe indications as to the calcium content of the pre-Cambrian ocean.

The actual calculation of about 900 typical analyses confirms the prevailing view that the Paleozoic and pre-Paleozoic limestones are more highly magnesian than the more recent limestones. The ratio of calcium to magnesium is nearly constant in the average limestones of the pre-Cambrian, Cambrian, Ordovician, and Silurian formations. That ratio rises abruptly in the average Devonian limestone and increases again greatly in the average Carboniferous limestone. In the Cretaceous limestones it reaches a maximum value which is very close to, or sensibly equal to, that characteristic of the average Tertiary and Recent limestones.

Detailed field work and microscopic and chemical study have indicated that the higher proportions of magnesium in the older limestones can not be explained by their having been more deeply buried and more metamorphosed than the younger limestones. The evidence shows that the magnesian content of the staple pre-Devonian limestone is original, in the sense that the magnesium carbonate was precipitated from sea-water. In many, if not all, cases the dolomite crystals may have been formed at or near the surface of the ancient calcareous muds by the interaction of the magnesian salts of the sea-water with the more easily precipitated calcium carbonate. Porosity of the sea bottom would aid this process, as it is today favoring the dolomitization of certain more porous beds in the Funafuti atoll.

In brief, the chemical composition of the ocean water, the conditions of life in the sea, and the marine limestones in general have all had a correlative evolution. The hypothesis founded on this central thought is at many points in this paper strongly charged with speculation; each item of speculation is offered not only as a means of intelligently grouping the many facts relating to this important theme, but also, and more especially, as an advertisement calling for new facts.

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GEOMETRY OF FAULTS[1]

BY HARRY FIELDING REID

(Presented before the Society December 29, 1908)

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INTRODUCTION

Two years ago Mr F. L. Ransome called attention to the confusion existing in the nomenclature of faults and noted that in the case of diagonal faults it is frequently impossible to say whether we are dealing with a normal or a reversed fault, or to determine whether a line at right angles to the fault-plane has been shortened or lengthened.[2] The discussion which followed confirmed Mr Ransome's statements. It also showed that the actual movements which have taken place in the case of faults in which there is a component parallel with the fault-strike have

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[1] I wish to acknowledge my indebtedness to Mr G. K. Gilbert, who kindly read over this paper in manuscript and made a number of important suggestions which have been embodied in the text.

Manuscript received by the Secretary of the Society January 9, 1909.

[2] "The directions of movement and the nomenclature of faults." Economic Geology, 1906, vol. i, pp. 777-787.

not been carefully studied, nor any methods described by which these movements could be determined; and a search through geological text-books and books on applied and field geology failed to discover more than a cursory treatment of this subject. I have for this reason thought it worth while to discuss the nature of the observations necessary to determine completely the movement at a fault and to show how this movement can be worked out from the observations. The subject is of very considerable importance to the mining engineer, to enable him to determine the position of faulted veins, and also to the dynamical geologist, for it is essentially necessary to know the actual movement which has taken place at a fault in order to infer from it the character of the forces which caused it.

NOMENCLATURE

The confusion of nomenclature makes it necessary to define the meaning of the words to be used. The names "normal" and "reversed" faults will be retained in their ordinary geometrical meaning without any inferences with respect to the forces producing them. The *displacement* in any direction of any surface—such as a stratum, dike, vein, or old fault, or of any line—is the length of the line joining the separated parts (actual or produced, if necessary) of the surface or line, measured in that direction; the *perpendicular displacement* is measured at right angles to the surface or line. The *offset* of a surface is the horizontal displacement, measured at right angles to the strike of the surface. For the total movement we shall use the word *shift*, which is represented by the line *ab*, figure 1. The projection *ac* of the total shift on a horizontal line parallel with the fault-plane will be called the *horizontal shift;* and the projection *cb*, on a line parallel with the fault-plane and at right angles to the former line, will be called the *dip-shift.* The *throw*, or *vertical throw*, is the difference in altitude of the two ends of the shift, and the *heave*, or *horizontal throw*, in the vertical plane at right angles to the fault-plane, is the horizontal component of the total shift at right angles to the strike of the fault-plane; it is also the horizontal projection of the dip-shift. The *stratigraphical throw* is the resolved part of the

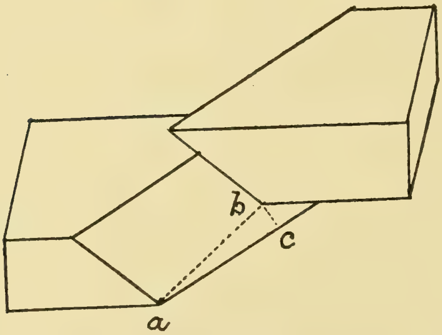

FIGURE 1.—*Displacement at a Fault*

total shift at right angles to the strata, or the perpendicular displacement of a stratum. It will be seen that when we are dealing with a strike-fault these terms correspond to the terms now in use. The only new word introduced is the word "shift," which practically defines itself; and the word *displacement* is used in the general sense and is not confined to any particular direction. The *hade* of the fault is measured by the angle between the fault-plane and the vertical, and is not, as some writers have used it, the equivalent of the fault-dip, which is its complement.

These definitions apply especially to cases of no rotation; where rotations occur the nomenclature is not confused.

A SYSTEM OF PROJECTION

When we consider faults which are diagonal to the strike of the strata, or strike-faults in which a component of the movement is parallel with the fault-strike, the total shift does not, in general, lie simply in a horizontal or a vertical plane, which we might use as a plane of reference; and it is not at all convenient to use an inclined fault-plane for this purpose. It is, therefore, necessary to use some method of projection to represent the various movements and the various surfaces we deal with, on a plane surface of reference. Fortunately there is a very simple system of projection, familiar to many geologists, by which this can be done; and this consists in representing the surface by its intersection with a horizontal plane, which we shall call the *horizontal plane* or the *reference plane,* and by contour lines drawn upon it. The horizontal plane can not correspond with an irregular topographic surface; but it may be chosen at the mean level of that surface, or at any other convenient altitude. This system of projection will be readily grasped if we keep in our minds a clear conception of the positions of the various lines and surfaces in space and use the diagrams to work out their quantitative relations.

A plane is represented by its intersection with the reference plane, which is a straight line, and is called its *trace,* and by a series of parallel straight lines representing its contours. These contours, however, may be omitted if we indicate by the side of the trace the direction and amount of the dip. Thus in figure 2 let tT represent the trace of a plane dipping to the east at an angle represented by δ. The position of any contour can be determined immediately as follows: Draw a straight line ta at right angles to the trace; lay off the angle δ equal to the dip and complete the right-angle triangle abt right angled at a; ab will then be the depth of the contour at a distance ta from the trace. This will readily be seen if we revolve the triangle about *ta* until it is vertical; *tb* will then lie in the plane under consideration. The triangle *atb* will be called the *dip-triangle.* From this triangle we see that *ab* is equal to *ta tan* δ; therefore with a table of natural tangents we can immediately determine the depth *ab* at any given distance, *ta,* from the trace; or we may determine it graphically from the dip-triangle itself. We shall use a heavy line to represent the trace of a plane.

Lines will be indicated by their projections on the horizontal reference plane, and for these projections we shall use broken lines. The lines themselves will be referred to as the *originals* of their projections. The points where the lines intersect important planes may be inclosed in small circles. The inclination of a line will be indicated in the same way as the dip of a plane. The dip-triangle of a plane will always be drawn so that if it is revolved about its horizontal line until it lies in a vertical plane, with the angle underneath, the hypothenuse will coincide with the dip, and a similar convention will be used for lines. This will remove all confusion as to the direction in which lines, or planes, slope.

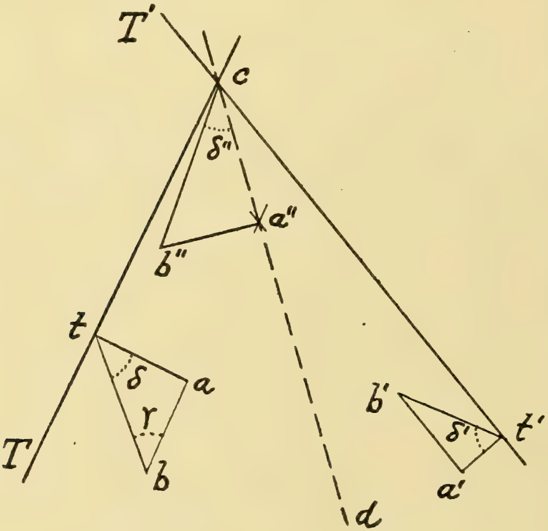

FIGURE 2.—*Intersection of two Planes*

The line of intersection of two planes will pass through the intersections of their traces; by drawing contours at the same depth on the two planes, their intersection gives a second point of the line, whose projection can then be drawn. We can determine the projection of the contours from the dip-triangle, *tab,* figure 2; for *ta* equals *ab cot* δ, or *ab tan* γ; and since γ is the complement of δ, we can use our same table of tangents; or we may make *ab* and $a'\,b'$ have equal values in the two triangles and determine the horizontal distances *at* and $a'\,t'$ graphically. The original of the point a'', the intersection of the two contours, *ab* and $a'\,b'$, will lie on both planes whose traces are T and T', and therefore on their intersection; the projection of this intersection will then be *cd.*

The inclination of the original of this line can be determined; for its depth below the surface at the intersection of the two contours is known, and this depth divided by ca'' gives the tangent of the inclination; that is, $\tan \delta'' = a'' b''/ca'' = ab/ca''$; or we may determine the inclination of the line graphically by drawing $a'' b'' = ab$ at right angles to cd, and the inclination δ is found by completing the triangle $ca'' b''$.

To determine the point where a straight line, whose projection is $t' c'$, figure 3, pierces a given plane, t, pass a plane through the line and let its trace be parallel with that of the given plane. This trace will pass through the point where the line cuts the reference plane. Draw a straight line from this point at right angles to the two traces and it will make an angle, θ, with the projection of the given line; let δ' be the dip of the line, and δ'' that of the plane we have passed through it; then $\tan \delta'' = \tan \delta' \cos \theta$; or we may determine δ'' graphically as follows: Lay off the inclination δ' of the line, and from any point, d', of its projection, draw $d' e'$, which will be its depth at that point. Draw $d' d''$ parallel with the trace, t', and it will be the projection of a contour on the plane t'; the depth of the plane t' at d'' will be $d'' e'' = d' e'$; draw $d'' e''$ and complete the triangle $t' d'' e''$, and the dip of the plane, t', will be δ''. Lay off the dips, δ and δ'' at t and t', and produce the lines until they intersect in c. The two planes will meet on the contour through c, whose depth, $bc = tb \tan \delta = bt' \tan \delta''$. The given line lying in the plane t' will intersect the same contour under c', which is therefore the projection of the point where it intersects the plane t. If the plane is the reference plane and the line is given by its horizontal projection and the depths of two points on it, such as the line ff', figure 7, we lay off these depths, fg^{iv} and $f' g^{iii}$, at right angles to the line, and draw $g^{iv} g^{iii}$; it intersects the line ff' in the horizontal reference plane at k; for if we rotate the triangle, kfg^{iv}, about ff' until it lies in a vertical plane, $g^{iv} g^{iii}$ will be the true position of the original line; or we may determine k by means of the proportion $kf' : f' f = f' g^{iii} = fg^{iv} - f' g^{iii}$.

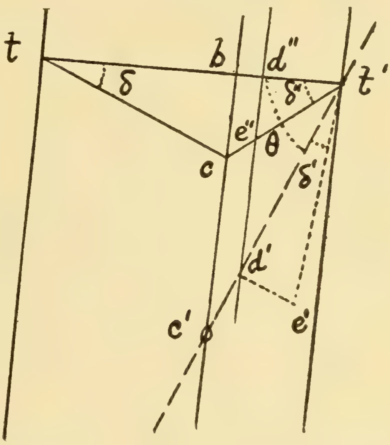

FIGURE 3.—*Intersection of a Line and a Plane*

To find the point where a horizontal line pierces a plane, draw the projection of the contour on the plane at the same depth as the line; the intersection of the projections of the line and of the contour will be the projection of the point sought. To find the depth at which a vertical line cuts a plane, find the depth of the contour immediately under the line.

If three points of a plane are given, we can readily find its trace and dip. Let *a, b, c,* figure 4, be the horizontal projections of the three points on a plane, and let these letters also represent their depths below the reference plane. Draw *ac* and lay off the depths of *a* and *c* at right angles to it; if *dg* is the depth, *b,* then the original of *d* will have the depth, *b; d* can be found from the proportion $ad; ac = a{-}b : a{-}c$. The line *bd* will be the projection of a contour on the plane. Draw *ak* perpendicular to *bd;* lay off the depths, *eg′* and *al*, at *e* and *a;* draw the line *lg′* intersecting *ae* in *k;* δ will be the dip of the plane, and a line through *k,* parallel with *bd,* will be the trace.

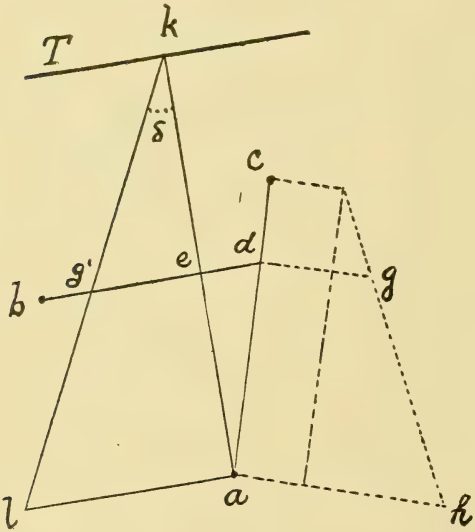

FIGURE 4.—*Plane determined from three Points*

If one point of a plane and the direction and amount of the dip are known, we can easily determine the trace on the reference plane. We pass a line through the point in the direction and with the inclination of the dip and find its intersection with the reference plane; through this intersection draw the trace at right angles to the dip. This is the method which will be frequently followed in finding the trace of a stratum or other plane on the reference plane; for, on account of irregular topography, observations will rarely be made directly on the horizontal reference plane itself. On the other hand, it is easy to determine the outcrop of any plane on an irregular topographic surface when we have given the trace of the plane on the reference plane and its dip. We draw the projections of the contours on the plane and on the surface, and intersections of the projections of contours having the same altitude will be points on the projection of the outcrop.[3]

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[3] Many examples of the determination of the locations of outcrops are given in Professor Konrad Keilhack's Lehrbuch der praktischen Geologie, second edition, pp. 174—.

Two lines may or may not intersect. They will intersect if the point of intersection of their projections represents points of equal altitudes on the two lines; otherwise they will not. Lines in the same plane always intersect unless they are parallel; and if lines intersect, the point of intersection of their projections will be the projection of their actual point of intersection. If we wish to determine the distance between two points, or the angle between two lines, we revolve the plane, containing the points or lines, around its trace until it is horizontal. All points and lines in it will then appear in their true relations to each other. We have virtually used this method in indicating the dip by the dip-triangle in the reference plane; other examples will be found farther on.

Classification of Faults

The displacement of a mass as a whole from one position to any other can always be represented by a parallel displacement, or translation, and a rotation. When the first and last positions are given the direction of the axis and the amount of rotation is fixed, but we are at liberty to choose the location of the axis at will, and we can then determine the translation necessary, with the rotation, to represent the total displacement of the mass. There are an indefinite number of ways of doing this, according to the location we choose for the axis of rotation. If there is no rotation, the displacement becomes simply a translation. If there is no translation, the displacement becomes a simple rotation.

We may therefore classify faults as follows:

- Parallel displacements.....
  - Plane strata..............
    - Strike-faults.
    - Diagonal and dip-faults.
  - Folded or contorted strata.
    - Strike-faults.
    - Diagonal and dip-faults.
- Rotatory displacements....
  - Simple rotation without translation.
  - Rotation with translation.

In parallel displacements all parts of the rock mass remain practically parallel with their original positions; whereas, when rotatory displacements occur, the rock, at least on one side of the fault-plane, rotates about an axis. For geometrical reasons we treat plane strata, faults, where parallel displacements take place, and other nearly plane surfaces as though they were true mathematical planes. If we deal with large areas, this assumption is far from true; but over small areas, even though it is not strictly accurate, it will not in general introduce any material error. A long fault is apt to have very different strikes in different parts of its course; we can then apply the methods here described to small parts of the fault separately, and we can determine, not only the similarities, but also the differences, of the movements in various parts of the fault. It is quite possible for a fault surface to be curved, even with parallel displacements, provided it is so shaped that one side can slide on the other along the shift without distortion; the surface will be cylindrical, and the contours on the surface will be similar curves all parallel to each other. We can apply the methods here described to this case, but we must draw the contours of the fault surface instead of merely using the trace and the dip.

Plastic distortions may change the form of the fault and other surfaces concerned during the shift or afterwards. It would then be an interesting problem of structural geology to determine, by a consideration of the possible movements of nearly rigid blocks and by a consideration of the forms of the surfaces and the distortions observed, what parts of the displacements were due to plastic movements and what parts to simple shifts on the fault. In some cases an approximate solution could certainly be obtained, though in others it might be impossible. We shall not treat of these complex movements, except in certain very simple cases, but shall consider that the displaced rock, at least over small areas, has moved without distortion, like a rigid body. The comparison of the movements thus determined at different parts of the fault would go far to reveal the plastic distortions.

PARALLEL DISPLACEMENTS

PLANE STRATA

Data required for determination of shift.—The complete determination of the shift which has occurred at a fault requires us to find the horizontal direction of the movement, its inclination to the horizontal plane, and its amount.[4] The determination of these three quantities requires three different measures; the nature of these measures will differ in different cases, but they must be independent. For instance, the displacements of two strata, or of two parallel dikes, or of a stratum and a sill, would only yield one independent measure; but the displacements of a stratum and a dike which have the same strike, but different dips, would yield two independent measures. The measures which can bs made are the displacements of strata, dikes, old faults or veins, and the azimuth and inclination of striæ on the fault-plane; the azimuth is determined by the compass, the inclination by the clinometer. We shall now see how these different measures may be combined to give the complete movement at the fault. It must be remembered that we can only determine the movement of one side relative to the other, and it makes no difference which side we regard as stationary.

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[4] We may, if we prefer, determine the components of the total movement in three directions at right angles to each other.

Strike-faults.—Geologists in the field often recognize the existence of a fault by the fact that certain strata are repeated or that certain strata are missing. We do not now consider the cases where these facts are due to unconformities or to folds, but we assume for the present that they are due to the existence of a fault. Frequently no other observations are possible; in this case the only determination which can be made is the stratigraphical throw. If certain strata are missing, it is necessary to determine the relative positions of the same stratum on opposite sides of the fault by means of the known thickness of the missing strata. If this cannot be done, we can merely infer which side has dropped stratigraphically relatively to the other; we cannot determine the amount of the movement. If this can be done, let *s. s'*, in figures 5 and 6, represent the two positions of the repeated stratum, and let δ be the dip. Then $as' = ss' \sin \delta$ will represent the stratigraphic throw, and it is quite evident that nothing further can be determined. The same displacement could be produced by a slip along the line *cb*, or along the line

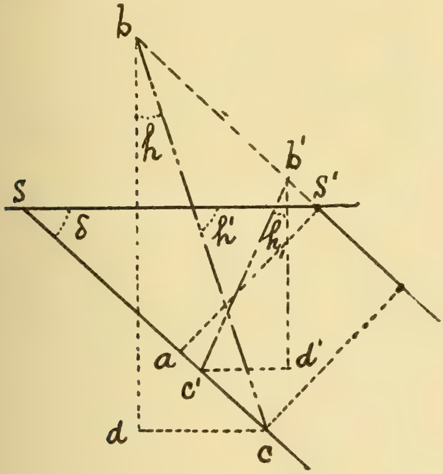

Figure 5.—*Repeated Strata*

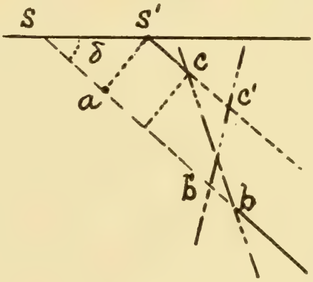

Figure 6.—*Missing Strata*

$c' b'$; therefore we do not know whether the fault is normal or reversed, nor can we tell whether a horizontal straight line at right angles to the fault-strike has been lengthened or shortened. If we are fortunate enough to find the fault-plane and can determine its dip, we can then determine the dip-shift, for this will be represented by the line between the planes of the disrupted stratum and parallel with the dip of the fault. For example, the dip-shift will be bc, which equals $as'/\cos(\delta + h)$. When the fault and the strata dip to opposite sides of the vertical (the fault is then represented by $b' c'$), we may use the same expression for the dip-shift, but we must make h negative. The heave, or horizontal throw, is given by the line $cd = bc \sin h = as' \sin h/\cos(\delta + h)$. The vertical throw, bd, equals $bc \cos h = as' \cos h/\cos(\delta + h)$. We evidently have all the elements of the displacement in the plane at right angles to the strata and to the fault.

If the movement has a component parallel with the fault-strike, we must use the system of projection given above to represent the observations. As the procedure in this case and in the case of a diagonal fault are exactly similar, we shall take the latter as more general.

Diagonal faults.—Case I: Given, the traces and the dip of a disrupted stratum. Let us suppose that we have determined the offset between T and t, the traces of a disrupted stratum, figure 7. If no other measures have been made except the dip, we can only determine the stratigraphic throw, which can be found from a vertical section at right angles to the traces of the stratum, as in figure 5. It can also be found in our system of projection as follows: Draw the traces t, t', figure 3, and at t lay off the angle δ, representing the dip, and at t' lay off the angle $\delta'' = 90° - \delta$, which will represent the inclination of the perpendicular to the two planes. The angle tct' will be a right angle, ct' will be the amount of the stratigraphic throw, bt' will be its horizontal projection, and δ'' will be its inclination.

Given, in addition, the trace and dip of the fault-plane. If, in addition, we are able to locate the fault-plane and to determine its dip, we can, by the method already given, determine the projection, ed, of the line of intersection of the fault-plane and the stratum, figure 7. A parallel line through e' will be the projection of the intersection of the fault-plane and the displaced part of the stratum. If we have no other observations we can not decide whether the fault is normal or reversed; all we can say is that some point on the original of ed has been moved to some point on the original of $e' d'$. These lines are parallel and they lie in the fault-plane; one lies in one part of the disrupted stratum and the other in the other part. We can, of course, determine the perpendicular distance between them by revolving the fault-plane about its trace until it becomes horizontal; the original of a point, f, of the line ef, whose depth is fg (found by laying off the dip-angle δ' at k', where the perpendicular from f to the fault trace falls) will be brought to g'', where $k' g'' = k' g$; and the line ef will be brought to eg''. The perpendicular, $e' n$, dropped from e' to eg'', will give the amount of the displacement at right angles to the original of ed; on revolving the fault-plane back to its proper position, n will come to p, and $e' p$ will be the horizontal projection of this displacement.

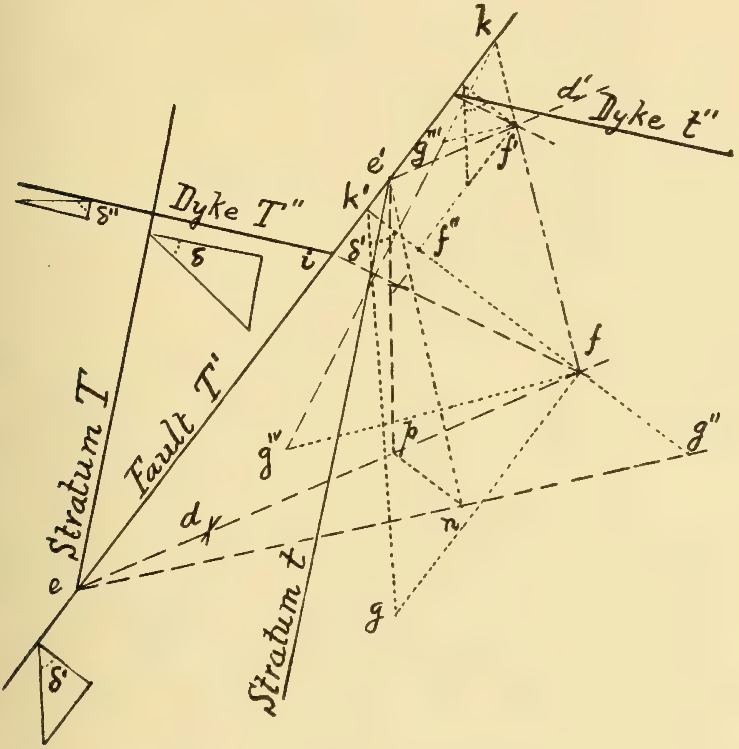

FIGURE 7.—*Determination of the Shift, Case I*

Given, in addition, the trace and dip of a disrupted dike. If we are fortunate enough to find a dike which has been cut by the fault-plane, and whose traces are represented by T'' and t'', we can determine the whole shift; if will be the projection of the line of intersection of the undisturbed dike with the fault-plane, and f, its intersection with the line *ed,* will be the projection of the point where the fault-plane, the stratum, and the dike met before the disruption. In the same way we find f', the projection of the meeting point after disruption; ff' will be the projection of the total shift. $f' g^{iii}$ is the depth of the original of f';

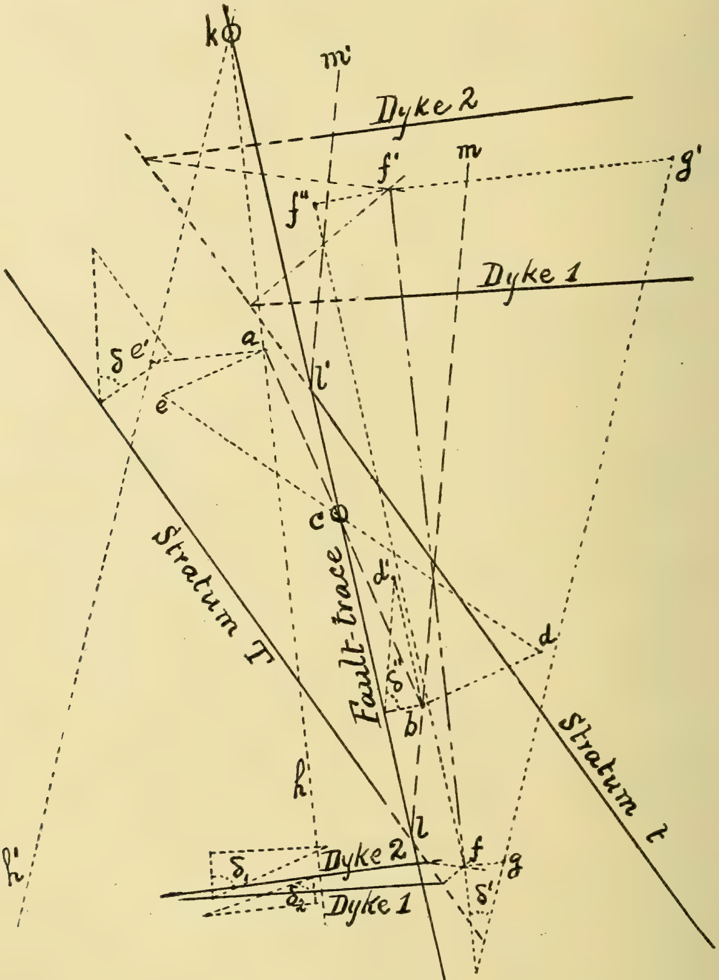
k
m'
Dyke 2
m
f'
g'
f''
Dyke 1
δ
e'
a
l'
e
c
Stratum T
Fault-trace
d'
d
δ
b
Stratum t
h
l
h'
δ1
Dyke 2
f
g
δ'
δ2
Dyke 1

FIGURE 8.—*Determination of the Shift, Case II*

$fg^{iv} = fg$ is the depth of the original of f; hence $g^{iv} g^{iii}$ is the total amount of the shift and fkg^{iv} is its inclination. The actual movement is known and all displacements can be immediately found. In this case the point of the stratum, *T,* at the original of f before disruption, moved up the fault-plane to the original of f', or a point of the stratum, t, has moved in the opposite direction. The horizontal line at right angles to the fault-trace has therefore been shortened by the amount equal to ff'', the horizontal projection of the line ff', at right angles to the fault-trace. If the stratum and the two dikes meet on the undisturbed side of the fault, they will not meet again on the displaced side; but their virtual meeting point can be determined by finding the meeting point of the three displaced planes produced.

Case II: Given, the traces, dips, and offsets of a stratum and of two dikes. Suppose we have not found the fault itself, but have found the traces of the disrupted stratum, T, t, figure 8, and have also found the parts of two dikes which have been disrupted by the fault. We proceed as in the former case; we find the projection, f, of the meeting point of the stratum and the two dikes before the disruption, and the projection f' of the point where their displaced parts meet. The line ff' will be the projection of the total shift; fg and $f'g'$ will be the depths of the originals of f and f' respectively; gg' will be the total amount of the shift, and δ' will be its inclination; $f''f'$ will be the lengthening of a horizontal line at right angles to the fault-trace.

Although we have determined the direction, inclination, and amount of the total shift, we have not determined the fault-plane, for there are evidently an indefinite number of planes which can contain a line parallel with the original of ff'. If we have found one point of the fault-plane where, let us say, dike 1 has been disrupted, we can still pass an indefinite number of planes through that point which would contain a line parallel with the original of ff', but if we have also found a second point where, for instance, the stratum has been disrupted, the fault-plane can be immediately determined. We shall suppose these two points to be the originals of a and b, and that they are not in the horizontal plane, but, on account of the topography, the original of a lies above, and that of b below, this plane. The altitudes of the originals of a and b would naturally be determined in the field; but, since one lies on dike 1 and the other on the stratum, we can find the altitude each must have by the ordinary method of the dip-triangle. We thus find that the original of a lies a distance ae above the horizontal plane, and that of b at a distance bd below it. The fault-plane must pass through the original of ab and contain a line parallel with the original of ff'; therefore it must contain a line through the original of a parallel with the original of ff'; ah will be the projection of this line. The trace of the fault-plane must pass through the points k and c, where the originals of ah and ab intersect the reference plane. Moreover, the fault-plane contains the original of

b, whose depth is bd; and a contour on the fault-plane through the original of b must have the depth bd; therefore lay off $bd' = bd$ through b and parallel with the fault-trace, complete the dip-triangle, and δ'' will be the angle of the fault-dip. At the time of the rupture the stratum, the projection of whose intersection with the fault-plane is lm, slipped diagonally down the fault-plane in a direction parallel with the original of ff' and at an angle less steep than that of the original of lm. A horizontal line at right angles to the fault-trace was lengthened by an amount, $f''\ f'$, but the intersection of the displaced stratum with the fault-plane (original of $l'\ m'$) will be *above* the intersection of the fault-plane and the undisturbed stratum (original of lm), and the fault would therefore be called a reversed fault.

Case III: Fault in igneous rock. Given the trace and dip of the fault-plane; the traces, offsets, and dips of two dikes, or *of one dike and an old fault-plane,* or *of any two planes which have been disrupted by the fault.* The construction in this case is exactly like that in case I.

Case IV: Given, the azimuth and inclination of striæ, and the traces, offsets, and dip of a stratum, or *of any plane disrupted by the fault.* Let T, t', figure 9, be the traces of the stratum; ff' the projection, and δ' the inclination of the striæ, the original of f' being the lower point. Let us find the total displacement of some point, d, on the trace, T. Through d pass a line parallel with the striæ; dd', parallel with ff', will be its projection; pass a plane through d, having Td for its trace and containing the original of the line dd'; its dip will be δ'', obtained by the method given on page 175. This plane will meet the displaced stratum, t', in the contour $h'\ e'$, obtained by laying off the dip δ at c', as shown in the figure, and finding the intersection, e', of the lines de' and $c'\ e'$; and therefore the original of line dd' will meet the plane in the same contour in the original of the point d'. dd' will therefore be the projection of the shift of d, and dg' obtained by laying off the angle δ' at d, or by drawing $d'\ g'$ equal to $h'\ e'$, will be its amount.

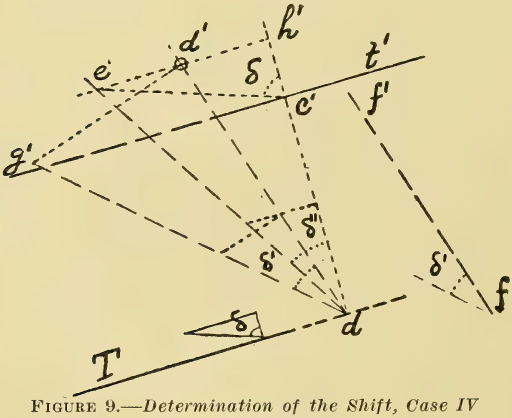

FIGURE 9.—*Determination of the Shift, Case IV*

We have not fixed the fault-plane, but if the direction of the striæ have been determined it is probable that the strike and dip of the fault-plane have been also. If they have, we can determine the projections of the lines of intersection of the fault-plane and the stratum, as in case I and figure 7; then draw a line parallel with the azimuth of the striæ connecting the two lines mentioned; the depths of the two ends of its original can be found, and thus its dip and the total shift.

If one side of the fault should be igneous and the other side stratified rocks, we can in general infer which side has been relatively raised, and we may be able to estimate the vertical throw from the thickness of the stratified rocks; but if the fault is diagonal with respect to the strata, a further complication is introduced. By following along the fault we may come to a place where the strata are horizontal; it is also possible that traces of the stratified rock, which have not been entirely eroded off, may be found on the igneous rocks, which would indicate the vertical throw and the horizontal shift; but we could not, without finding the hade of the fault, determine whether the fault were normal or reversed. This, however, is rather a case of folded than of plane strata.

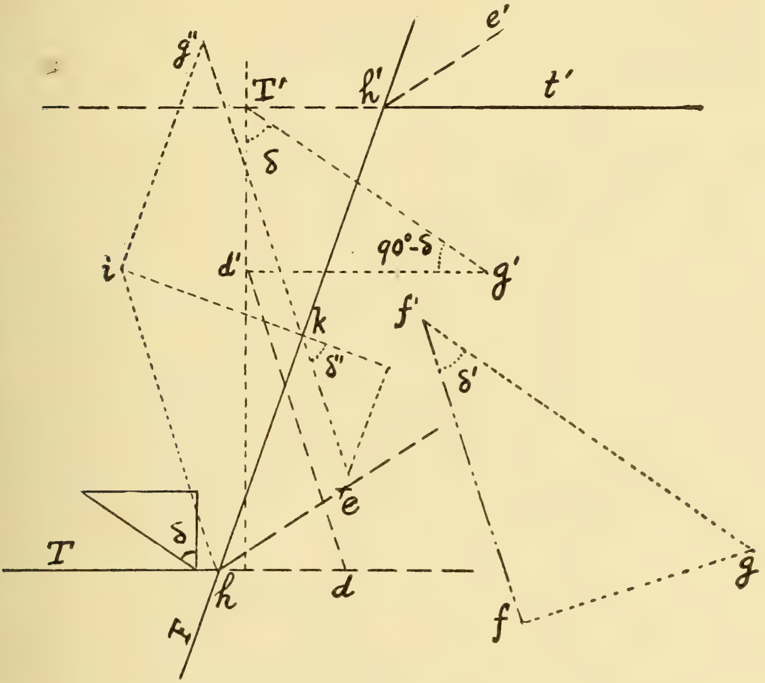

FIGURE 10.—*Determination of the Displacement of a Plane, Case V*

Not infrequently the strata on one or both sides of the fault-plane have been bent up in a direction opposite to their displacements. In finding the displacements we must use the position of the strata outside this distorted portion; the shift thus determined refers to the relative displacement of the rock in general on opposite sides of the fault and not to the actual slip on the fault-plane, which may be somewhat less.

Case V: Given, the total shift, in amount, direction, and inclination; to determine the displacement of any plane, such as a stratum or vein. Let ff', figure 10, be the projection of the shift, its inclination being δ', and f' being the projection of the higher point; the difference of level of these two ends of the shift is fg. Suppose a plane is given by its trace, T, and by its dip, δ. A point of this trace, which was originally at d, has been moved to the original of d', a distance equal to and parallel with the original of ff', the height of the original of d' above d equals fg. The displaced part of the stratum passes through the original of d' and dips to the north at an angle δ. It will reach the horizontal plane at a point, T', found by drawing $d'\,T'$ at right angles to the trace T, and erecting $d'\,g' = fg$ at right angles to $d'\,T'$, and at g' laying off the angle $90° - \delta$; $g'\,T'$ meets $d'\,T'$ on the trace of the displaced plane; for if the triangle $d'\,g'\,T'$ be rotated about $d'\,T'$ until g' is vertically above d', the line $g'\,T'$ will lie in the dip of the displaced plane and will cut the horizontal plane at T'. The trace, T', can then be drawn parallel with T. If the trace, F, of the fault is given, we can find the fault-dip, δ'', and consequently the projections he and $h'\,e'$ of the fault intersections with the strata T and T'; the stratum T will not extend to the right of he, nor T' to the left of $h'\,e'$.

FOLDED OR CONTORTED STRATA

The changes in the shape of the strata prevent us in this case from using the very simple construction given above, and if the fault should be a strike-fault it is in general necessary to make a pretty complete geological section in order to compare the two sides and determine the movement which has taken place at right angles to the fault-strike. The movement parallel with the fault-strike would have to be determined as in the former case, by the dislocation of a dike or of some other plane. In the case of diagonal or dip-faults our problem is somewhat easier. The crest of an anticline or the trough of a syncline furnishes a line which has been dislocated by the fault, equivalent, in our former case, to the intersection of two dikes, so that we can immediately say that a point of this line on one side of the fault has been displaced to a point of the displaced line on the opposite side of the fault. If we can determine the strike and dip of the fault-plane, the whole movement can be determined. This can also be done if we can find the strike, dip, and offset of a dike or other broken plane.

ROTATORY DISPLACEMENTS

SIMPLE ROTATION WITHOUT TRANSLATION

In this case the fault surface will be a surface of revolution, with the axis of rotation as its axis of revolution; it is only under these conditions that the movement can take place and contact be maintained between the two sides. The axis is apt either to be at right angles to the fault surface or not actually to intersect it at all; for if it should intersect the fault surface in an acute angle, the surface must, in the neighborhood of the point of intersection, envelop the axis like a cone—a form which has never been observed.

Professor Jaggar has suggested that some faults occur in which one side has rotated as a block about an axis at right angles to the fault-plane.[5] I am not sure that movements of this kind occur on a large scale in nature; certainly the California earthquake fault, which Professor Jaggar refers to, is not an instance of it; and it is difficult to understand what allowable forces would cause such a rotation. We must remember that the continuity of the rock must exist except at the actual break, and that the displacement of faults is taken up near their ends by plastic or elastic distortion. Moreover, in very large masses the rock can not be expected to act like a rigid body. If the angle of rotation is small, we can decide if the main part of the rock rotates about a single axis by determining the displacement at different parts of the fault by methods already given; then by a comparison of these displacements we can see if they all represent a rotation around the same axis. If they do, the directions of the movements must be all at right angles to the radii drawn from a single axis, and the amounts at different points must be proportional to the distances of the points from the axis. The axis can then be easily determined, as pointed out by Professor Jaggar, by finding the intersection of lines drawn at right angles to the directions of the movements. If the angle of rotation is large, we have merely to determine the rotations of lines in the plane of rotation, and see if these rotations are equal in different parts of the fault. If the fault surface is nearly plane, its intersections with the strata afford excellent lines for determining the rotations.

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[5] "Economic geology," 1907, vol. ii, p. 60.

Small rotations, of limited extension, and with the axes at right angles to the fault surface, apparently occur in all ordinary faults. If we follow along a fault we finally come to a point where it dies out, and we find in different parts of its course that the amount of the vertical throw has varied. This, of course, requires a certain amount of bending of the strata, and this bending constitutes a rotation of that part. The rotation is not the same at different parts of the fault's course, and may even vary in its direction, in which case we should have gentle folds whose axes are at right angles to the fault-strike. The rotation, of course, is greatest where the rate of variation of the vertical throw is greatest, and this is very apt to occur near the ends of the fault. If the strata are nearly horizontal, a slight rotation will make a great difference in the direction of the strike, and thus the strata on opposite sides of the fault will strike at each other. If, however, the strata are highly inclined, the variation in the strike will be extremely small. Where the rotation is small, the error introduced by treating the displacement as a simple translation, without considering the rotation, would be unimportant.

Where the rotation is appreciable, it is best to suppose the strata rotated back through an angle until they become parallel on opposite sides of the fault. We can then determine the displacements by the methods already given; and we must add, as a part of the description of the fault, the amount of rotation which has taken place. We must decide by general conditions, such as the relation of the strike and dip of the strata to the same quantities beyond the ends of the fault, whether one or both sides have been rotated. As this is a case of rotation and translation, it might be treated by the method of the next section; but the method just given is simpler and might be preferable, where the main part of the displacement is a translation accompanied by rotations unevenly distributed in the various parts of the mass.

When the axis does not intersect the fault surface, the fault usually occurs only on one side of the axis, and on the other the rocks yield by plastic bending. Movements of this kind apparently take place when large blocks, like the Sierra Nevada mountains, for instance, are tilted up. A section of the fault surface in a vertical plane at right angles to the axis would be circular, but its ground plan might have almost any shape, dependent upon the distribution of the forces causing the movement. We can not look upon such a large mass as acting like a rigid body; there is a certain amount of distortion as the fault dies out near its ends, and the rotation is probably not constant along the fault or at right angles to it, the differences being permitted by small plastic distortions. The folded strata of the Sierras would make it impossible to determine, by their positions, the variations in the rotation of different parts of the mass; but physiographic methods might yield more definite results. The Wahsatch mountains offer another example of a large tilted block; its western boundary fault must be a surface of revolution.

A landslide where the mass holds its form and is not broken is an example of this kind of rotation on a small scale.

Another fairly common example of apparent rotation with the axis parallel with the fault surface is the upturning of the edges of the strata on the downthrow side of a fault, which usually extends but a short distance from the fault-plane. This may be due to a general shear, to a large number of minute faults parallel with the main fault, or to the bending up of the individual strata accompanied by a slight slipping of each stratum upon its neighbor, just as cards slip upon each other when a pack is bent. The last method seems to me the one we should expect to occur most frequently. This is not a true rotation of a block as a whole, but is a distortion of the rock-mass, suggesting a rotation on account of the tilting of the strata. It is better to look upon such a quasi-rotation as a disturbance in the neighborhood of the fault and, as already noted, to make our observations for displacements at a greater distance, beyond the zone of upturning.

Where a simple rotation has occurred it is easy to determine its axis and amount, if we know the plane of rotation. Let figure 11 be a section in a plane at right angles to the axis; let *a* and *a*′ be the disrupted parts of the same stratum before and after rotation; extend the directions of these parts until they meet in O'; δ will be the angle of rotation. Erect a perpendicular to the middle point of the line connecting *a* and *a*′, and find a point on it at which the line *aa*′ will subtend the angle δ; this point, O, will be the axis about which the rotation took place.

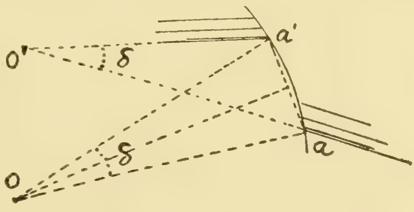

FIGURE 11.—*Simple Rotation*

ROTATION WITH TRANSLATION

Where both rotation and translation have taken place we may either suppose a particular point of the rock to have been moved directly to its new position, and the mass then rotated around an axis through this point, or we may represent the whole displacement as made up of a rotation about a properly chosen axis and a translation along that axis; that is, by a movement similar to that of a screw. The fault surface will be a screw-surface, though it may approximate, or even become, a cylinder or a plane; in the latter case the movement will reduce to a simple translation or a simple rotation. It may be a question whether a composite displacement of this kind occurs in nature on a large scale; but, as the method of treating this case is the same as that of finding the axis of a simple rotation, when the observations do not make the direction of the latter immediately evident, we shall take up the more general case. This case is perfectly general, and includes every possible displacement of a rigid mass without distortions.

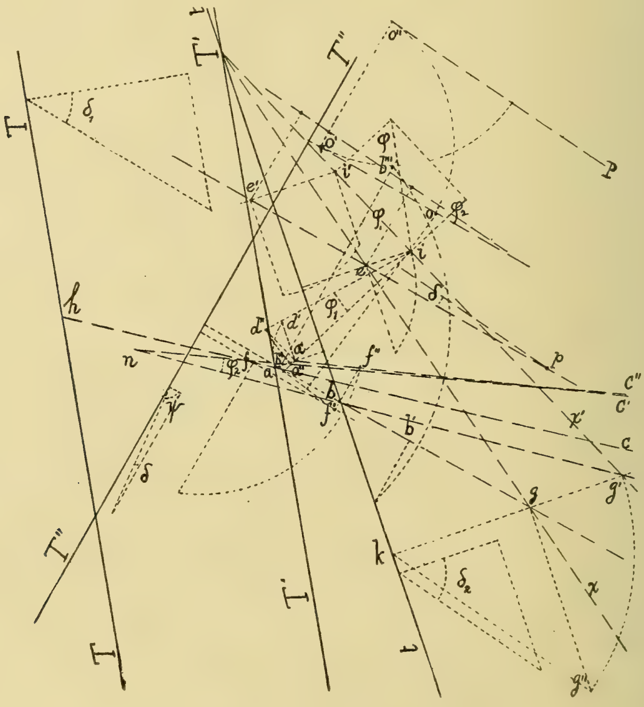

FIGURE 12.—*Rotation and Translation*

It is quite evident that if three points in a body are fixed, the body itself is fixed; and if the displacements of three points are known, the displacement of the body is known. Three points determine a plane and the directions of lines and the positions of points in the plane. When we wish to determine the rotation which a rock-mass has experienced, we may then determine what rotation is necessary to bring a plane of the undisturbed mass into parallelism with its displaced position, and what further rotation is necessary to make a line in this plane parallel with its position in the displaced plane. If a translation has also occurred, its amount can easily be determined. Let us take a stratum for the plane, and for the line, the intersection with it of a dike or vein. The intersection of this line by a second dike will determine a point.

In figure 12 let *TT* be the trace of the undisturbed stratum, and δ_1 its dip; let *tt* and δ_2 be its trace and dip after displacement; let the original of line *hc* in the first stratum be displaced into the original of *bg*, and let the original of point *f* go over into the original of *b′*; the problem is to find the character and amount of the total displacement. The method is to rotate the plane *TT* about its intersection with *tt* until the two coincide, and then to rotate the plane *TT* about an axis perpendicular to it until the originals of the lines *fc* and *bg* are parallel; the direction of the axis and the amount of the total rotation can be calculated from these two partial rotations.

As *TT* and *tt* do not intersect within the limits of the figure, we introduce an auxiliary plane, *T′ T′*, parallel with *TT*, intersecting *tt* in the original of *T′ x*. The original of *ac* will be parallel with the original of *hc*, *a* lying on the trace *T′ T′*. In order to bring the two planes into coincidence we must first make the original of *T′ x* horizontal; we therefore rotate the whole mass about *tt* through the angle δ_2, and the former line comes into the horizontal plane in *T′ x′*; this is done as follows: *g* is the projection of a point on the intersection of the two planes, and also on the original of line *bg*; draw *gk* perpendicular to *tt*, and at right angles to this line lay off *gg″*, the depth of the original of *g*; with *kg″* as radius, draw the arc *g″ g′* intersecting *kg* in *g′*; *g′* will be the new position of the original of *g*. *T′* and *b*, being on the trace *tt*, are not moved by the rotation, and therefore *T′ g′* and *bg′* are the new positions of the originals of *T′ x* and *bg*. Similarly *a′ c′* becomes the new projection of the original of *ac*; *a* goes over into *a′*, with *a′ d′* as the new depth of its original. So far we have rotated the whole mass and have made no changes whatever in the relations of its different parts. We have really merely changed our plane of reference.

Now, leaving the plane *tt* horizontal, we rotate the plane *T′ T′* around *T′ x′* until the two planes coincide. We have seen that the original of *a′* on the plane *T′ T′* lay at a depth *a′ d′*, or *a′ d″*; and therefore, to raise this point to the horizontal plane, we find it must be rotated through the angle φ_1, which immediately appears if we consider the triangle $a' id''$ as vertical. When the rotation through the angle φ_1 is accomplished the two planes coincide, and the original of $a' c'$ becomes $a'' c''$. On rotating $a'' c''$ about a vertical axis through the angle φ_2, it coincides with bg'. We have rotated $T' T'$ through an angle φ_1 around a horizontal axis $T' x'$, and then around a vertical axis through an angle φ_2. We can combine these two into a single rotation, just as we can two simple translations. At i lay off a distance towards i' proportional to φ_1, and vertically downward a distance proportional to φ_2; on completing the parallelogram the diagonal will give the direction of the resultant axis, and its length will be proportional to its amount. In representing a rotation by a length of its axis we measure the length positively in the direction in which the rotation would carry a right-handed screw. By measuring $\varphi_1 = a' \ id''$ and $\varphi_2 = g' \ nc''$, we find them respectively 15° and 10.3°; and φ becomes 18.2°; ii' will be the projection of the axis, which will dip down from i.

We must now bring our whole mass to its original position by rotating back through angle δ_2 about tt. The original of i will be brought to the original of e, that of i' to that of e', and the axis of rotation will become the original of ee'; its dip, δ, is readily found by laying off, at right angles to ee', at e, and e' respectively, the depths of their originals and joining the ends of the lines thus drawn. As this line does not meet ee' within the limits of the figure, we find δ by drawing an auxiliary line parallel with it, and which intersects ee' at a convenient point, p. We have found the direction of the axis of rotation; that is, its projection is ee', its positive direction is from e towards e', its dip is δ; its amount is 18.2°; but its actual position may be anywhere; and if we choose a position for it we can then determine what translation is necessary, in addition, to make the undisturbed stratum coincide in all respects with its displaced part. In particular we may choose the proper position of the axis in order that the translation shall be along it. For this purpose let $T'' \ T''$ be the trace of a plane at right angles to the axis; its dip will be $\psi = 90° - \delta$. Revolve everything up through the angle, ψ, about this trace; the axis of rotation (original of ee') will become vertical and f will go to f', and b' to b''. A point, o, can now be found on the perpendicular bisector of $f' \ b''$ at which $f' \ b''$ will subtend the angle of rotation, φ; this then will be the position of the axis, for f' will be brought to b'' by a rotation, φ, around this point. The original of f' is at a distance $f' \ f''$, and the original of b'' is at a distance $b'' \, b'''$ above the plane, and therefore the translation parallel with the axis consists in raising f' through the difference of these distances. Rotating everything down around $T'' \, T''$ through angle, φ, to come back to the original position, o goes to the original of o', whose depth is $o' \, o''$; and if at o'' we draw the line $o'' \, P$, making the angle ψ with $o'' \, o'$, the point of intersection of $o'' \, P$ and $o' \, o$ will be the point where the axis of rotation intersects the horizontal plane, $o \, o'$ will be its projection and its positive direction, δ will be its dip, and φ its amount; $b'' \, b''' - f' \, f''$ will be the translation. If this latter quantity should come out zero, then the whole displacement would be a simple rotation; but in general it would be impossible to assume in the beginning that this condition held.

We have treated this case as though the strata were plane, but this is not at all necessary. If the fault were diagonal to the strata, we might be able to construct the geological section on opposite sides of the fault, and we could determine the rotation by considering the displacement of a plane tangent to the apex of an anticlinal, and the line of tangency; or if a dike cut the strata, the plane of the dike and a line in this plane tangent to the apex of an anticline could be used equally well; the intersection of the dike with the apex of the anticlinal would furnish a point whose displacement would determine the translation.

Special Difficulties

There are two kinds of accidents which may materially interfere with the determination of the actual movement of a fault. The first of these is an unconformity. This may be entirely covered on the downthrow side, so that only the strata above it are exposed, and on the upthrow side all the strata above the unconformity may have been eroded away. The strike of the strata will in general be different on opposite sides of the fault, but this, of course, will have nothing to do with a rotation. We must reconstruct, if possible, the position of the strata below the unconformity on the downthrow side; otherwise we can only determine at best a limit to the amount of the vertical throw.

The second kind of accident that may interfere with consistent results is due to the fact that the whole movement at a fault may have been made up of a series of steps, and it is quite possible that dikes or veins may have been formed at a time between the steps; their displacement would not then represent the whole movement on the fault. Moreover, it is by no means necessary that the direction of movement of all the steps should be the same, and therefore striæ which may be found may only represent the last step, and if their direction were taken as the direction of the whole motion, we should be led to erroneous conclusions. It is difficult to say just how these various accidents may be avoided; each case must be treated by itself; but in general, if we have more observations than are necessary to determine the movement, we can compare the results obtained by combining them in different ways, and if the results are all accordant we may feel pretty sure that we have determined the full movement. For instance, if we have given, not only the offsets of three independent planes, but also the direction of the striæ, we have several methods of determining the total shifts. If they do not give the same results, we may be sure that the offsets of the planes were not wholly due to the movement which produced the striæ.

Possible Displacements

When faults extend over very long distances they are usually not very straight, and sometimes they curve considerably. The form a fault will take will depend on the strength of the rock along its course and the distribution of the forces which produced it. It is hardly probable that where the curvature is great the displacement could have a strong horizontal component; but it might be either a translation or a rotation. In the former case the intersection of the surface with the plane containing the movement would be a straight line; in the latter it would be a circle. If both a translation and a rotation existed in not too unequal proportions, it is probable that the fault surface would become nearly a circular cylinder, and its course along the earth's surface would not be far from straight. These surmises must not be applied too vigorously; it is only in small masses that the rock may be considered rigid, and the displacements might be very different in the different parts of a long fault as a result of plastic deformations.

Where two faults intersect and neither suffers an offset, we must conclude that the blocks in the four angles have suffered displacements parallel with the line of intersection of the two faults.

Sometimes the rock is found to be broken up by numerous faults into a series of blocks. If the blocks defined by three or four faults do not have their edges parallel, but are wedge-shaped, we may be sure that the movements on the different faults occurred at different times, and we should expect the older fault-planes to show offsets; for if the block moves on several fault-planes at once, it must move parallel with their several lines of intersection, which must therefore be parallel with each other. Wedge-shaped blocks are sometimes represented in geological sections bounded by intersecting faults with the movement shown by the displacement of the strata, but with no offset shown on either fault. This is an impossible arrangement.

Not infrequently blocks are represented as displaced and tilted in ways which can not, apparently, be accounted for unless some of them have been plastically deformed; and there is no evident reasons why these particular blocks should have been singled out for such deformations. These matters are mentioned here in order to call attention to the necessity of considering what displacements are possible with blocks which are nearly rigid, when sections must be drawn from incomplete data.

CONCLUSION

The varieties of complex faulting are very great, and no attempt has been made to treat them all. The method of treatment has been fully set forth and a number of examples given. The method is so simple that it can be mastered in a very short time; and other cases can then be treated without difficulty. The projections show at a glance the complete structure. Where folded strata exist their forms must be indicated by their proper contours. The confusion due to the multiplicity of lines can be avoided by using different surfaces, by rubbing out construction lines after they have served their purpose, and by drawing separate diagrams to represent the structure between successive selected levels where, as in the case of mines, the tunnels increase the complexity of the drawings. To persons unfamiliar with geometrical projections, the method may at first seem difficult to use; but the nature of the problems requires the consideration of space relations, and the method here given is probably the simplest possible method of dealing quantitatively with these relations; and without quantitative methods we can not get quantitative results.

Sometimes the character of the movement on a fault can be inferred from certain general considerations, such as the prevalence of normal or reversed faulting in the region, from the general nature of the forces which have been active, or from a consideration of the general surface distribution of the rocks. All of these methods are valuable where more accurate ones can not be used; but it must be remembered that the results represent the judgment of the observer and are not true determinations. Geology is still far from being an exact science, but the effort should be made to introduce accurate methods wherever it is possible.

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TRAP SHEETS OF THE LAKE NIPIGON BASIN[1]

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INTRODUCTION AND GENERAL REVIEW

DISTRIBUTION OF THE TRAPS

Along the north shore of lake Superior from the Slate islands to Pigeon river, and extending over an area reaching to more than 100 miles north of the Canadian Pacific railway, the most prominent geologic feature is the occurrence of large areas in which trap sheets predominate. Within this area practically every salient feature of the topography is found to be associated with these trap sheets. Along the southern edge of the district, and extending for about 40 miles north of the Canadian Pacific Railway line, the traps are constantly found in association with Keweenawan and Animikie sediments. In the northern part of the area, in the basin of lake Nipigon, residual patches of Keweenawan sediments are frequently found associated with the traps, but there are numerous localities where the igneous rock rests directly upon the older Archean rocks.

The variegated, bold, and picturesque topography seen along the line of the Canadian Pacific railway from Rossport to West Fort William, Red Rock at the mouth of the Nipigon river, McKay mountain at Fort William, Pie island, and Thunder cape are a few of the many salients familiar to any one who has journeyed by boat or rail to Port Arthur or Fort William. The gorge of the Nipigon river from north of lake Jessie is cut through one of these immense sheets, and the less well known but more picturesque canyon which forms Pijitawabikong bay, a few miles east of the Nipigon river, is also cut through the same sheet.

Usually these trap sheets are nearly horizontal and of great extent. The largest single continuous area, so far explored, lies in the basin of lake Nipigon, south and southwest of the lake itself. The sheets occur either as sills from 4 to more than 50 feet in thickness, intercalated within the sandstones, shales, or dolomites, or in the form of capping sheets from 12 to more than 500 feet in thickness. These caps stand at the summit of the local stratigraphic column and their upper surface usually is a tableland or mesa.

PETROGRAPHY OF THE TRAPS

As to the petrographic characters of the trap sheets it may be noted that diabase is by far the most abundant rock, olivine being present frequently in large amount. Structurally it may pass from a typical diabase, the prevailing rock, to a coarse gabbro or olivine gabbro, or locally to a fine grained porphyrite. The ophitic structure is the most prominent and widespread. The texture, except at the contacts with the

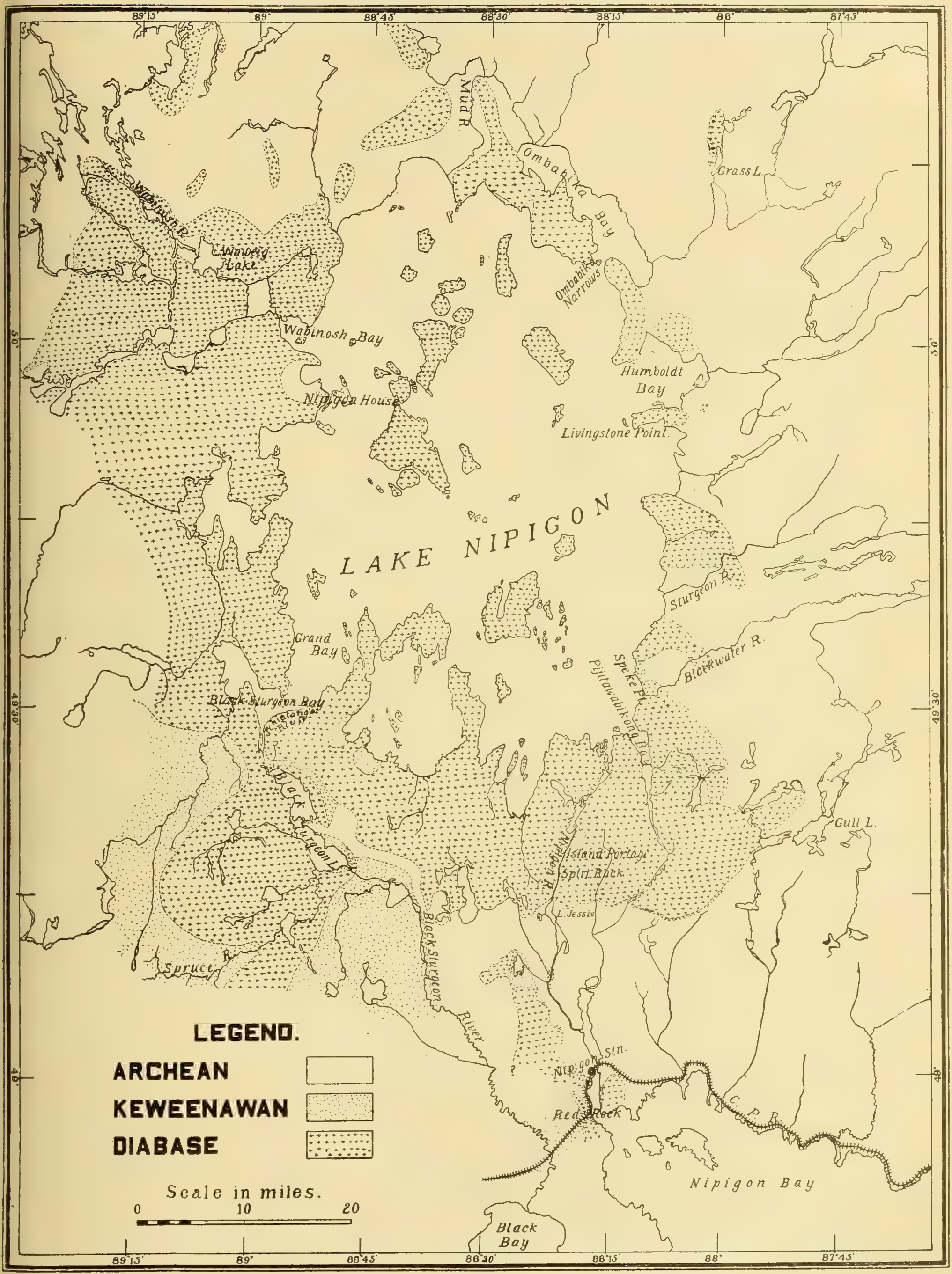
89°15'
89°
88°45'
88°30'
88°15'
88°
87°45'
50°
49°30'
49°
Mud R.
Ombabika Bay
Ombabika Narrows
Grass L.
Wabinosh Bay
Nipigon House
Humboldt Bay
Livingstone Point
LAKE NIPIGON
Sturgeon R.
Blackwater R.
Grand Bay
Black Sturgeon Bay
Speke P.
Pijitawabikong Bay
Gull L.
Island Portage
Split Rock
L. Jessie
Black Sturgeon L.
Black Sturgeon River
Spruce R.
Nipigon Stn.
Red Rock
C. P. R.
Nipigon Bay
Black Bay
LEGEND.
ARCHEAN
KEWEENAWAN
DIABASE
Scale in miles.
0
10
20

FIGURE 1.—*Sketch Plan of Lake Nipigon Basin*

Showing the areal distribution of the principal bedrock formations earlier rocks, varies from medium to coarse; usually it is nearly uniform throughout the thickness of the whole sheet, except close or near to the basal and upper contacts, even where the sheets are several hundred feet in thickness. The sheets of diabase, with a few local exceptions, are remarkably constant in their petrographic characters over nearly the whole area. They are invariably holocrystalline and are never amygdaloidal.

VIEWS AS TO THEIR ORIGIN

The earlier students of the district regarded these diabase sheets, in whole or in part, as volcanic flows, the lower and thinner intrusive sheets being considered as contemporaneous with the sedimentary rocks with which they are associated, while the capping sheet was designated the "Crowning overflow" by Sir William Logan. Later work by Ingall[2] and by Lawson[3] has combatted these ideas, and the view so admirably set forth by Lawson has come to be generally accepted.

Lawson's thesis is (page 29):

"There are no contemporaneous volcanic rocks in the Animikie group.

"None of the trap sheets associated with the Animikie, whether of the nature of 'caps' or intercalated sheets, is a volcanic flow.

"These trap sheets are all intrusive in their origin and are of the nature of laccolitic sills."

Lawson further summarizes the data on which he founds this thesis in the following statement (page 44):

"I. The trap sheets associated with the Animikie strata are not volcanic flows because of the combination of the following facts:

"1. They are simple geologic units, not a series of overlapping sheets.

"2. They are flat, with uniform thickness over more than one hundred square miles in extent, and where inclined the dip is due essentially to faulting and tilting.

"3. There are no pyroclastic rocks associated with them.

"4. They are never glassy.

"5. They are never amygdaloidal.

"6. They exhibit no flow structure.

"7. They have no ropy or wrinkled surface.

"8. They have no lava breccia associated with them.

"9. They came in contact with the slates after the latter were hard and brittle and had acquired their cleavage, yet they never repose upon a surface which has been exposed to subaerial weathering.

"II. They are intrusive sills because of the combination of the following facts:

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[2] E. D. Ingall: "Mines and mining on lake Superior." Geological survey of Canada, 1888, vol. ii, part 2, section H, pp. 42, 46, 79, 80, 99.

[3] A. C. Lawson: "The Laccolitic sills of the northwest coast of lake Superior." Minnesota Geological Survey, Bulletin viii, 1893.

"1. They are strictly analogous to the great dikes of the region: (*a*) In their general relations to the adjacent rocks and in their field aspect. (*b*) In that both the upper and lower sides of the sheets have the facies of a dense aphanitic rock, which grades toward the middle into a coarsely crystalline rock.

"2. They have practically a uniform thickness over large areas.

"3. The columnar structure extends from the lower surface to the upper surface, as it does from wall to wall in dikes.

"4. They intersected the strata above and below them after the latter had been hard and brittle.

"5. They may be observed in direct continuity with dikes.

"6. They pass from one horizon to another.

"7. The bottom of the sedimentary strata above them, wherever it is observable, is a freshly ruptured surface.

"8. Apophyses of the trap pass from the main sheet into the cracks of the slate above and below.

"9. The trap sheets, particularly at the upper contact, hold included fragments of the overlying slates.

"10. They locally alter the slates above and below them."

For purposes of discussion the diabase sheets may be divided into two great groups: That group of sheets both the upper and lower surfaces of which are known or can be readily inferred, and a group consisting of all those sheets whose under surface only is known—the group of sheets which forms the various topographic "caps" throughout the whole region.

With reference to the first group, the observations of the writer, conducted over a wider area, emphatically confirm Lawson's conclusions as outlined above. With reference to the capping sheets, the writer's observations are in accord with Lawson so far as the areas examined by both are concerned, but data obtained largely in the basin of lake Nipigon lead him to make a somewhat different interpretation of facts noted both by Lawson and himself, and to different conclusions.

Scope of the present Discussion

The writer wishes to confine the present discussion wholly to the consideration of the nature of the relations which now exist, and possibly formerly existed, between that group of sheets of diabase which now form the "caps" and the underlying rocks. So far as all other masses of diabase within the area are concerned, his observations confirm in every respect those of Lawson. Hence that there are a group of diabase sheets in this region which are not volcanic flows but which are intrusive sills of a laccolitic type is *not* a subject of discussion in this paper.

With reference to the "caps," it must be recognized at the outset that the only contact surfaces we can study are those at the base. The character of the upper surface and the nature of the contacts, if any, can be a matter of inference only. Possibly a few of the "caps" belong to the first great group of sheets in which the character of the upper surface can be directly inferred from evidence available. The greater number of caps exhibit no direct evidence as to the character of their upper surface, and it is with these that the present discussion deals.

Negatively they exhibit none of those characteristics which are usually associated with volcanic flows—there are no pyroclastics, they are never either glassy or amygdaloidal, never exhibit ropy or wrinkled surfaces, have no associated lava breccias, and the nature of the contact with the underlying rocks shows that the latter were hard and brittle before traps came into the area. So far as negative evidence is concerned, they exhibit none of those features which are usually considered as characteristic of volcanic flows.

Descriptions of critical Areas

IN GENERAL

The nature of the basal contacts of these sheets and the general character of the sheets can be best understood from the study of a selected few from a very much larger number of concrete examples. The examples which are cited in the succeeding paragraphs are only a few typical instances in which the relations of the traps to the adjacent rocks are clearly depicted. They have been selected because they are in localities readily accessible and because they are all, with the exception of Red Rock, within the Nipigon basin and are directly associated with the principal area of diabase.

GORGE OF THE NIPIGON RIVER

At Island portage, on the Nipigon river, about 5 miles above lake Jessie and in the heart of the gorge, Archean gneisses are exposed in the channel of the river. On the east there is a high cliff of gneiss rising about 350 feet above the river, which has, I believe, usually been mistaken for diabase, as it is nearly continuous with the diabase cliffs which swing in from the east at lake Jessie and continue up the east side of the Nipigon gorge almost to lake Nipigon. On the west side of the river, at Island portage, is a coarse pegmatitic granite rising about 250 feet above the water.

The area of Archean here exposed in the gorge of the Nipigon, completely surrounded and partly capped by diabase, is about 4 square miles. At lake Jessie the diabase is found nearly 300 feet lower, with possibly not more than 100 feet of sediments between it and the underlying Archean. The south edge of this sheet has been traced from a point nearly 30 miles east of the Nipigon and for 12 miles west. The base usually rests on sediments throughout this distance of over 40 miles, the sediments in turn resting on a very uneven surface of Archean rocks.

The position and attitude of the Archean island in the diabase near Island portage suggest a pre-sedimentary monadnock, partly denuded before the advent of the diabase, buried by it, and subsequently uncovered by various erosion processes, the latest event in the geological history being the formation of the Nipigon gorge.

TCHIATANG BLUFF

At the southwest corner of lake Nipigon is a deep bay, lying between diabase headlands, called Grand bay. An inner bay at the bottom of Grand bay, on the route leading south to Black Sturgeon lake, is called Black Sturgeon bay. The south shore of this latter bay is bounded by a high bluff, the relief being over 700 feet. In the narrows between Grand bay and Black Sturgeon bay, a little more than half a mile from the base of the bluff, is a small island, known as Gneiss island, the bedrock exposed being gneiss. Between this island and the bluff soundings gave a depth of 66 feet. The entire bluff, to the summit, is diabase, and the highest point lies back from the cliffed front of the bluff (325 feet) about half a mile and stands about 650 feet above the lake. At three points on the face of this bluff masses of sandstone, now almost a quartzite, are found in the diabase. At least one of these is about 25 feet in thickness and stands nearly vertical. About 2½ miles west of Gneiss island, at the foot of the bluff, another mass of gneiss outcrops, rising at least 150 feet above the lake, and capped by trap. Four miles south of here is a ridge of granite-gneiss which can be traced in a southeast direction, with varied expression and at times partly covered either by sediments or by diabase or by both for a distance of 20 miles, where it joins the large area of Archean rocks lying east of the Black Sturgeon river. The two small exposures of gneiss seen at Tchiatang bluff are topographically at a lower level than the main area to the south, and the second one noted probably represents the tip of the north end of a long ridge of Archean rocks.

Following the face of the bluff south to the narrows leading to the portage on the way to Black Sturgeon lake, there is a large mass of sandstone in the diabase just east of the narrows. This sandstone has a dip of about 80 degrees and is probably an inclusion in the diabase.

Four miles south of the bluff and about 1 mile east of Black Sturgeon lake, there is a large area of sediments resting directly upon the Archean, the actual contact and the lower basal beds being exposed. About 2 miles inland the diabase overlies these beds. It is not known whether there are any sheets of diabase intrusive in these beds. East of the south end of Black Sturgeon lake the same sheet of diabase rests directly upon Kewatin rocks. Hence in the vicinity of Black Sturgeon bay and Black Sturgeon lake we find the upper diabase sheet resting directly upon Archean gneisses and granites, Kewatin schists and Keweenawan sandstones and dolomites, five different types of rocks of three formations, and in addition there are some inclusions of sandstones in the diabase standing in various attitudes from nearly horizontal to vertical.

SPRUCE RIVER GORGE

The main stream running southeast from Black Sturgeon lake is a river of the same name. Through most of its course from the lake to Black bay, on lake Superior, the Black Sturgeon river flows along a lowland bounded on the southwest by a cuesta formed of Keweenawan sandstones and dolomites, the strata having a slight southwesterly dip. On the northeast side of the lowland is an extensive area of Archean oldland.

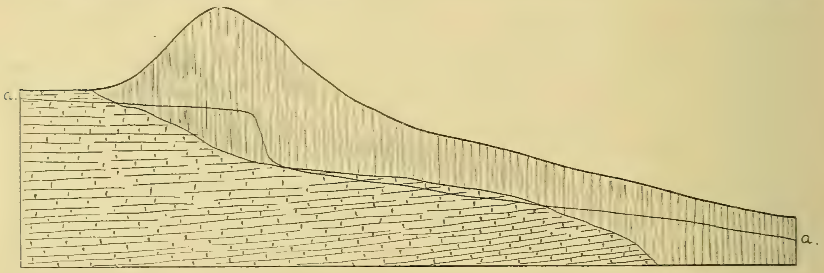

FIGURE 2.—*Section on Spruce River, 10 Miles southwest of Black Sturgeon Lake*

The profile of the stream bed is shown at "a"

The cuesta on the west rises about 300 or more feet above the river, and in places it is capped by remnants of diabase sheets. At one point in the bed of the river there is also an outcrop of diabase, but the relations of this isolated mass to the surrounding rocks are unknown. The escarpment which forms the edge of the cuesta can be traced from just above the Canadian Pacific Railway bridge to a point some 15 miles west of the south end of lake Nipigon, where it terminates. Outlying remnants of the sediments are known in several localities still farther northwest.

About 10 miles southwest of the Black Sturgeon lake the Spruce river, an important tributary of the Black Sturgeon river, flows down the face of the escarpment through a gorge cut in diabase, and eventually it reaches Black Sturgeon lake. Above the gorge the river flows in a channel cut in red Keweenawan dolomites. On approaching the edge of the escarpment it enters a gateway formed by the edges of one of the diabase sheets, which here rises fully 350 feet above the upper surface of the sediments in which the upper part of the channel of the river is carved. The stream in flowing through the gorge cascades and falls over diabase. Near the foot of the principal falls, about 90 feet below the level of the river above the gorge, greenish dolomites are exposed in the bottom of the channel and the sides are bordered by diabase. Down stream about 2 miles from the head of the gorge and probably about 170 feet below it, no further sediments are encountered and the stream channel is located on diabase. Numerous exposures of diabase between this point and Black Sturgeon lake make it seem probable that below the escarpment the whole area is immediately underlain by diabase. Sediments again appear from beneath the diabase not far from the point where the river enters Black Sturgeon lake. There can be no question but that in this locality a diabase sheet (at least 300 feet in thickness) lies along the edge of the cuesta, descends its front, and overlies a very large portion of the lowland in the immediate foreground and probably as far east as Black Sturgeon lake.

NIPIGON HOUSE OUTLIERS

Just north of Nipigon House, on the side of a hill of granite porphyry, and covering an area of less than half a square mile, is a small detached mass of diabase lying in a local hollow, the main part of the hill rising behind it. In other hollows on the same ridge are two small patches of basal sandstone and a second area of diabase. On the west end of Jackfish island, less than half a mile away, diabase is found at water level in immediate contact with the same granite porphyry.

About 6 miles north of Nipigon House, on the Inner Barn island, in Wabinosh bay, the remnant of the same diabase sheet has a thickness of about 600 feet. On the mainland south of the island other contacts between the diabase and the underlying granite are found, and some boulders of granite were also found in the diabase near the bottom of the sheet.

WABINOSH VALLEY

About 8 miles northwest of Nipigon House the Wabinosh river enters Wabinosh bay on lake Nipigon. Ascending the Wabinosh river toward the northwest, at Waweig lake, about 8 miles upstream, granites and gneisses are exposed near the shores of the lake and at a number of points in the bottom of the valley in which the river runs for the next 12 miles of its course. On either side diabase bluffs rise to an elevation, in round numbers, of 300 feet above the valley. Ascending these bluffs on the north side of the river valley and descending on the other side, at a distance varying from 1 to 2 miles from the river and at a height of between 145 and 160 feet above it, the granite gneiss is again encountered. The north edge of the diabase sheet thus is shown to abut against the side of an ancient valley in the Archean, and the depth of this valley was at least 150 feet. The preserved portion of the diabase sheet between the valley of the Wabinosh and the Archean highlands to the northeast of it now lies on the side of this old Archean valley.

OMBABIKA NARROWS

At the northeast angle of lake Nipigon is found one of the most interesting contacts of the district. The remnants of the diabase sheet have, in the vicinity of Ombabika narrows, a thickness of about 400 feet. On the north side of the narrows, just opposite the small island which divides the channel into two parts, the diabase flowed over rocks which had previously been eroded in such a way as to produce an undulating surface (or a warped surface). Subsequent erosion and glaciation have removed almost all of the diabase. Because of the position of the high ridges of diabase on either side of the narrows and because of the relations which the fronts of these cliffs bore to the direction from which the movement of the ice-sheet took place, erosion was especially active at this point, and the present surface, also a warped surface, is remarkably smooth. It has happened that over an area of several hundred square feet glaciation stopped at such a point that the present surface intersects the old pre-diabase warped surface in such a way that small areas of trap now occupy small hollows in the old surface, and, in a low cliff, sections of contacts in both vertical and horizontal planes are exposed.

At the west end of the island, in the narrows, there are a number of large and small granite boulders, derived from the immediately underlying Archean rocks, included in the diabase, with their upper surfaces planed off by the glaciation.

Within 2 miles of the narrows, toward the south, there are at two points very small exposures of a white quartzite with the diabase overlying, actual contacts being observed. Along the shore for 8 miles south of the narrows there is a narrow but nearly continuous strip of granite-gneiss exposed along the shore, the diabase rising in a ridge behind it.

On the northwest side of Humboldt bay, 8 miles southeast of the narrows and across the ridge of diabase which forms the main axis of the South peninsula of Ombabika, there are several areas both of granite-gneisses and Kewatin schists overlain by traps, actual contacts being seen.

On the east side of the north arm of Humboldt bay, about 2 miles from the contact between Kewatin schists and the diabase, the remnant of the trap sheet rests on Keweenawan sandstones; these in turn rest on granite. This area of sandstone is an isolated patch, with a minimum thickness of 50 feet. Since the diabase is found in actual contact, not only with the sandstones but also with the underlying rocks in adjacent areas, the contact is an unconformable one.

POSSIBLE REMNANTS OF OLD SOILS IN SITU

Within the Nipigon basin the greater number of contacts noted between the base of the remnants of the capping sheets of diabase and the underlying rocks were in areas where the Keweenawan sediments had largely been removed prior to the volcanic extrusion. In some four places, two of which have been mentioned above, boulders of Archean rocks have been found within the diabase close to the basal contact. Contacts between Keweenawan sediments and the igneous rock are also frequently found, but the best examples lie to the south of the Nipigon basin, along the line of the Canadian Pacific railway, in the area that is underlain chiefly by these sediments and the area in which the intrusive sills are so abundant.

Near the mouth of the Nipigon river, 3 miles southwest from Nipigon station, the railway track skirts the foot of a diabase-capped bluff known as Red Rock (from the characteristic color of the underlying sediments). At this locality (mile post 66, from Schreiber) the diabase sheet ascends across the beds to a height of about 140 feet, and the upper part of the sheet seems to rest nearly conformably on the upper beds. Where the diabase crosses the truncated edges of the lower beds, close to the railway track, between the base of the sheet and the undisturbed portion of the beds is a mass of broken rock at least 10 feet in thickness at one point and probably thicker elsewhere. This breccia consists of small fragments of the sediments, many of them partly rounded and the whole now recemented and bleached to a color lighter than that of the parent beds. The recemented beds seem to have a slight downward dip toward the ascending trap sheet.

At mile post 67, on the opposite side of the same ridge, are more exposures of a similar breccia, not in immediate contact with the diabase sheet. Nearly midway between these two points one of the railway cuttings passes through a dome in the sediments in which many of the thin shaly beds are crumpled, while the heavier beds are folded or faulted locally. While there are no exposures of diabase in the exposed portion of the core of the dome, its form and structure strongly suggest that the strata are arched up by a laccolitic mass below.

Lawson cites the local unconformity between the diabase and the sediments as an example of the intrusion of a laccolitic mass of the diabase across the beds. We have, however, no information as to the actual character of the upper portion of the capping sheet, and in the absence of this positive information the writer would interpret the section differently.

At first sight the apparent downward dipping of the edges of the beds at the contact with the diabase suggests monoclinal faulting. Directly opposite, across the river, similar sediments also capped unconformably by diabase, form a similar bluff, standing at almost precisely the same level, the distance between the two bluffs being less than a mile. If there were monoclinal faulting, accompanied by the intrusion of the diabase along a plane in the fault zone, not only would the occurrence of escarpments of nearly equal height on opposite sides of the fault plane be improbable, but the lifted block would be the block *above* the trap sheet, not the one *below*, and in this case both blocks are *below* trap sheets. Again, if the molten diabase had been forced upward from below along a fracture plane, it seems probable that if it disturbed the edges of the strata through which it passed it would tend to bend them *upward*, in the direction of flow, rather than downward. Where the diabase was in a very fluid condition, as presumably it was in this case from the nature of the crystalline structure of solidified magma, where fracturing was produced along the line of the intrusion, small fragments would almost certainly have been washed out into the diabase, and it would have insinuated itself between other fragments nearer the parent beds, but in no case were phenomena of this character noted. The fragments are fairly uniform in size, no very large blocks being noted, and are frequently rounded at the corners and edges, the whole mass being recemented with a material that was probably derived from the beds themselves.

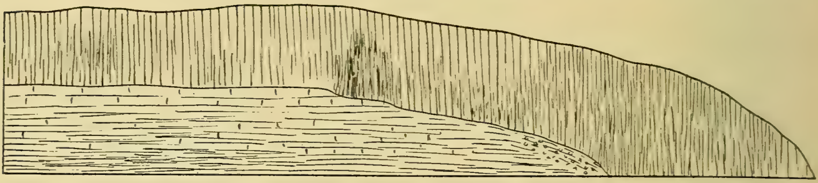

FIGURE 3.—*Section at Red Rock at the Mouth of the Nipigon River*

Intersection of Keweenawan strata by diabase, showing a small mass of supposed old soil breccia at the base of a pre-diabase cliff. One hundred and forty (140) feet of sediment are capped by 125 feet of diabase.

The block of sediments now exposed in section above water level very strikingly resembles such a ridge as could be duplicated many times among similar sediments, a flat-topped ridge fronted by a nearly bare sandstone cliff with a small talus at the base. The apparent downward drag of the beds at the contact between the breccia and the diabase is precisely similar to the soil drag found on steep faces of escarpments or slopes where the edges of thin beds containing shale members are exposed.

The writer is thus inclined to regard the breccias found only along the base of the hill as old soil breccias and the unconformity at this point as evidence of extensive erosion previous to the incursion of the trap.

An almost precisely similar breccia, in which many of the fragments are distinctly rounded, occurs near the post-office about 1½ miles east of Ouimet station (between mileposts 87 and 88), where it is also associated with, but only partially concealed by, a trap sheet—both at the foot of a slope and at its summit.

Again, at mileage 97¾, is a mass of very similar material consisting of fragments of red arenaceous dolomites lying in a hollow in granite and not now associated with any trap sheet.

The breccia found at the base of Red Rock, on the east side of the ridge, is in immediate contact with diabase and is only a small fragment of material similar to that which is found in several other localities not always associated with diabase sheets at the present time and not necessarily occurring at points where an intrusive mass has forced its way across strata. Under any other circumstances these fragments of waste rocks would unhesitatingly be regarded as remnants of an old soil cover. Except for the fact that they are recemented, they are almost precisely similar to the waste masses found in many other places associated with these same rocks today.

DISCUSSION OF THE EVIDENCE

SURFACE FLOWS VERSUS INTRUSIONS

Obviously the "capping" sheets of diabase, the group under consideration here, must have been either surface flows or intrusions. Were the original upper surface of the sheets preserved, it is extremely probable that there would be no difficulty in determining to which group they belonged. If they were surface flows we would expect to find the upper layers glassy, amygdaloidal, with traces of flow structure, occasionally perhaps associated with lava breccias or other pyroclastics. If intrusions, we could expect to find traces of the overlying sediments, or, internally, at or close to the former upper contact, the diabase would at times contain fragments derived from the old cover, and would always show a progressive diminution in the size of the grains of the constituent minerals as the contact was approached, precisely the same as is shown in all cases where both upper and lower contacts are known. Unfortunately it happens that all traces of the actual character of the upper portion of these sheets has been lost. In the Lake Nipigon basin alone there can be no question but that more than 80 per cent of the original volume of the mass of diabase that once was present has been removed, assuming that it had even a minimum thickness of between 600 and 700 feet (600 feet being the actual thickness of the remnants of the sheet in several places). When it is remembered that at the very summit of the thickest sheets known we find no change in texture indicating that an upper limit is being approached, it seems conclusive that before erosion began the sheets were very much thicker than their thickest remnants are today. While it would be rash to give any figure as a possible maximum based on the data now available, still if a minimum of 1,000 feet is allowed it would be found that more than 90 per cent of the volume of the original sheets has been removed from the area of nearly 6,000 square miles here under discussion.

Whatever may be the accuracy or inaccuracy of the approximations given above, an enormous amount of erosion undoubtedly has taken place, and in view of the fact that no record has been preserved as to the actual character of the upper part of the upper sheets, even if intrusive, the non-occurrence of any phenomena that can be associated with a volcanic flow must be regarded as a negative argument of very slight weight. In this case it is an argument of equal weight for both types of invasion, since each type has a characteristic upper surface under normal conditions. In fact, the preservation of upper layers that were more or less glassy and porous—the characteristic feature of most surface flows—would be extraordinary in a locality where the erosion has been so extensive, for such a surface would be even more susceptible to the action of erosive agents than either sediments or the upper surface of an intruded sheet.

It must also be considered that the features characteristic of the upper portion of a flow are confined to a few feet of the upper parts of the sheet. If there were a number of successive flows, following one another at intervals, so that the upper surfaces of the earlier ones had had the opportunity of cooling before the next flow came upon it, it is very probable that remnants of these surfaces would have been preserved.

A comparable instance is that of the Columbia lava fields, which cover an area of 200,000 square miles. The lava fields are built up by a number of separate flows, and the thickness varies from between 300 and 400 feet along the edge of the canyon of the Columbia to 3,700 feet, according to Le Conte, in the Cascade mountains near Dalles.[4] Russell describes the rock as usually a compact bluish black basalt with frequently a well defined columnar structure, "but also at times it is vesicular and scoriaceous, especially on the surface of sheets."[5]

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[4] American Journal of Science, series III, vol. 7, 1874, p. 168.

If, in the Lake Nipigon area, the lavas were very fluid, and if the flows followed one another closely, so that the earlier flows had not had time to solidify before the later followed upon them, or if there were only one large flow, the fluid lava would tend to accumulate in the basins and hollows of the invaded district, would heat the underlying rocks, possibly even re-fusing parts of the lava that had cooled on the first contact with the cold underlying beds on which it rested, and would remain fluid for a very long time, giving ample opportunity for the development of the crystalline texture so characteristic of the basal portion of the remnants of the sheets.

In this event the characteristic upper surface would be confined to the highest members only, and below a certain limiting depth the cooling of the mass would proceed as if it were a laccolitic mass below a sedimentary cover. For this reason also no argument as to the nature of the upper surface and as to the character of the intrusion can be based on variations in the texture of the crystalline rock. While the marked uniformity of the grain of the rock, except that close to the base of the sheets, suggests slow cooling, nearly simultaneous solidification throughout the greater portion of the mass of the sheet, and the existence of a cover, it offers no evidence as to the character of that cover.

UNCONFORMITIES OF THREE TYPES

General characteristics.—The occurrence of numerous unconformities is an established fact. Broadly, they are of three types:

The diabase sheet appears to truncate the edges of the nearly horizontal beds of sedimentary rocks *in situ* on Archean rocks.

The diabase rests on an erosion and uneven surface which truncates the structures of metamorphic Archean rocks.

The diabase rests on an uneven surface which truncates both Archean metamorphics and overlying later sediments—rocks of two or more formations.

Examples of each type.—Contacts of the first type are particularly numerous along the line of the Canadian Pacific railway. Reference has been made to the unconformity at Red Rock. A number of other examples are described by Lawson, more particularly, however, with respect to contacts between the diabase and underlying Animikie rocks. One of the most striking of Lawson's illustrations is reproduced here.[6] The unconformity in the gorge of the Spruce river also belongs to this group.

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[5] I. C. Russell: A geological reconnaissance in central Washington. U. S. Geological Survey, Bulletin 108, p. 21.

The explanations offered by Lawson and Ingall on the one hand and by the writer on the other, so far as they apply to these major unconformities, are diametrically opposite. In so far as these unconformities alone are concerned, the writer's verdict would be "not proven;" but when the various other unconformities are also considered, the balance of evidence seems to be strongly in favor of the latter explanation.

Contacts of the second class are numerous all around lake Nipigon. One of the most striking, that at Ombabika narrows, has been described in some detail, and attention has been called to the inclusion of boulders of the underlying rock in the diabase. Another example from near Nipigon House has also been cited and the occurrence of included boulders noted. There are also a number of other localities where masses of diabase, covering areas varying from about 1 acre to over 10 square miles, show actual contacts with an eroded Archean surface, and in some instances they contain detached blocks of Archean rocks similar to the bedrock on which they rest. The diabase masses occur on the tops of ridges and on the sides of valleys cut in the Archean (as at Wabinosh river, Nipigon House, and Tchiatang bluff) as well as in the bottoms of valleys. Archean valleys with a relief of a minimum of 150 feet are found to have masses of diabase located on their sides.

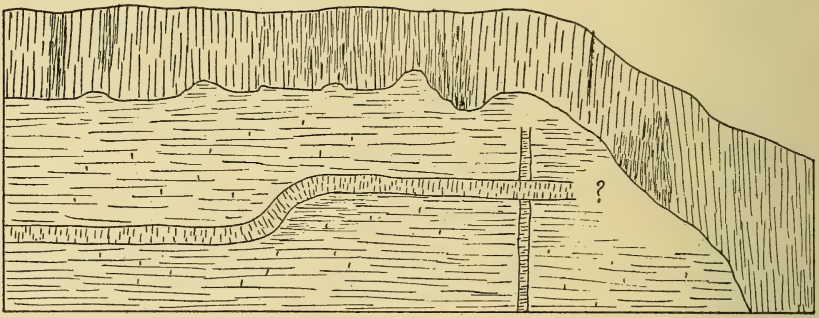

FIGURE 4.—*Diagrammatic Section near the Extremity of the Point between Big Trout and Pigeon Bays*

Showing the relation of the trap sills to the Animikie strata. (After Lawson)

The contacts of some of the smaller remnants of diabase sheets and the underlying rock show in detail the nature of the surface over which the diabase flowed and show that it was very intricate. There are many instances in which it can be shown that what appear to a traveler in the valleys to be high ridges of diabase rising above the adjacent depression are merely the edges of a dissected sheet of diabase, the present remnants now lying on the sides of old valleys cut in Archean rocks. Since the diabase is harder and more compact near contacts with other rocks, a reasonable explanation of the occurrence of this type of ridge is that the remnant of diabase is preserved where it lies largely because of its relation to the underlying rock and because of the texture thereby developed in this part of the sheet in the process of cooling. The high cliffs at Tchiatang bluff, where there is a relief of over 700 feet and diabase for at least 650 feet of this height, may be a case in point. The whole core of the bluff may possibly be Archean and the diabase only occur as a sort of plaster over its face.

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[6] Lawson: Op. cit., figures 1, 2, 3, 4, and 5.

The third type of unconformable contact has been illustrated by the description of the vicinity of Island portage, on the Nipigon river. Other examples cited are Tchiatang bluff and Humboldt bay, the latter being mentioned in connection with the Ombabika Narrows area. About ten contacts of this type have been examined by the writer, well distributed over different parts of the area, and it has been definitely established that the unconformity they indicate is not confined to any specific locality.

Discussion.—As has already been pointed out, the first type of unconformity has been explained either by the theory of a flow over an eroded surface or by assuming that the diabase was intruded across the beds. In the latter event it appears to the writer that certain evidence of this intrusion would be found at the contacts in the relationships which would then exist between the intruding rock and the edges of the fractured strata. This direct evidence is lacking, and, so far as the first type of unconformity is concerned, conclusive evidence has not been cited.

The second and the third types of unconformity have not, so far as the writer is aware, been previously discussed in print. There are but two possible ways in which they can have been brought about. The diabase must have flowed over an eroded surface or it must have been forced in to its present position along the surface of contact between an overlying cover and the rocks with which it is in contact.

Naturally the surface of contact between the sedimentary rocks and the underlying Archean would have been the locus of a number of lines of least resistance (or a plane of least resistance). Had the Archean surface been only moderately even, it is possible that it would have lain in the plane of least resistance; but the surface is an undulating one, with a moderate relief of at least 300 feet and in places more than this. In detail some parts of the surface are extremely intricate, yet we find numerous instances in which the diabase occupies not only major depressions in the surface, but has even insinuated itself into minor irregularities. It has done this not in a few localities, but in many places widely distributed. Had it insinuated itself between an overlying cover and the rock on which it now rests, normally one would expect to find numerous small remnants of the sediments in the bottoms of the major hollows, at least, rather than to find so complete a stripping as seems to have taken place. In the second place, the edges of the sheets, with the sediments underlying, have been followed and examined for many miles and by many observers, and no single instance has been recorded where an intruded diabase sheet has followed the sinuosities of the contact surface between the sediments and the underlying Archean. In other words, while in the whole area numerous sheets have been intruded into the sediments in addition to the sheets that now form the "caps," yet in no instance has one of them been found to have intruded itself along the supposed plane of weakness at the contact between the sediments and the underlying rocks.

In the case of unconformities of the third type, under the intrusive theory the diabase must have occasionally been unable to insinuate itself along the intricate surface of the Archean and must have broken across the beds of the sediments to a higher horizon, leaving a remnant firmly attached to the original basement, and again descending after the obstructing mass was passed—an improbability not only because of the physical difficulties involved, but also because at the contacts, so far as recorded or examined, no evidence of violent disruption or intrusion has been found.

Again, numerous contacts between the sediments and the Archean show that usually the basal beds are arkoses or conglomerates, and contain at least a few pebbles, cobbles, or boulders, derived from the underlying rock. In four widely separated localities, yet each in the vicinity of unconformable contacts between the diabase and two other formations, boulders of the underlying Archean have been found in the diabase at or close to the contact. The diabase in actual contact with these boulders is fine textured, but it is not glassy, and the zone of alteration, even in the immediate vicinity of one boulder about 5 feet across, is very narrow, from which one can infer that the boulder lay in the fluid or semifluid diabase long enough to become heated through, and that it had but little effect on the cooling of the diabase magma in its immediate vicinity.

No fragments of any sandstone or other cement material similar to that found in the basal conglomerate was found either in the diabase or clinging to the boulders, so far as seen.

It seems very improbable that the several masses of diabase in which these boulders now lie were intruded between the basal beds similar to those in adjacent masses of sediments and the Archean rock on which the trap containing these boulders now rests.

COLUMNAR STRUCTURE

Columnar structure is a feature characteristic of all the sheets, whether distinctly intrusive or possibly surface flows. In nearly every instance it extends from the lower surface to the upper surface, as it does from wall to wall in dikes. Structures of this type, however, are not confined strictly to sills. We find that the flows of both the Snake river and the Columbia river lava beds exhibit the same type of structure. It must also be pointed out that with respect to the capping sheets we know only the base of the sheet and possibly its middle parts, the upper part having been removed. There are also many localities where horizontal jointing is as well developed as the vertical jointing by which the columnar structure is produced. In very many instances (three localities are: east side of Pijitawabikong bay; near Speke point on the east side of lake Nipigon; and the west side of the portage into Waweig lake from the south) this double system of jointing is well developed, and a moderate amount of erosion along the fissures has slightly rounded the exposed corners of the joint blocks, so that the face of the cliff, sometimes for many hundreds of square feet, closely resembles an ancient wall. The resemblance to a wall is very close and remarkable, because the individual blocks are strikingly uniform in size and are usually oblong in section, the horizontal joints being usually closer to one another than the vertical ones.

On many of the thicker sheets so well is horizontal jointing developed that the vertical columnar structure which the cliff faces of these sheets present is largely due to the accident that gravity—which causes some of the joint blocks to fall down the fronts of the cliffs while others remain standing as columns—happens to act in a vertical direction only.

Summary of the Evidence available

IN FAVOR OF INTRUSIVE SILLS

The arguments in favor of regarding the "caps" as intrusive sills may be briefly summarized as follows:

1. Entire absence of any of those features that are usually associated with the upper parts of a surface flow—glassy matrix; amygdaloidal, porous, or basaltic texture; flow structure; associated volcanics, either lava breccias or pyroclastics.

2. A medium to coarse crystalline texture, usually indicative of a slow

rate of cooling, such as would normally take place only at some considerable distance below the surface.

IN FAVOR OF SURFACE FLOWS

1. The very widespread occurrence of unconformities between diabase sheets and underlying formations.

2. The occurrence of boulders of granite and gneiss and schist in diabase, the latter resting on similar rocks *in situ* in localities where there is direct evidence that before the advent of the trap the underlying rocks were buried beneath the sediments similar to those now present, near by, under the same diabase sheet.

3. The occurrence of old soils *in situ* at the bases and on the sides of sedimentary ridges, the whole being covered in places with a diabase cap.

4. The nicety of the adjustment by which the diabase sheets have fitted themselves to the underlying topography. While the upper surface[7] of the residuals of the capping sheets are everywhere fairly uniform in height, the base of the sheet has adjusted itself to a topography where the relief was at times as much as 300 feet.

5. The mechanical problem which arises in explaining the numerous unconformities, especially those on the embossed Archean surface, by the theory of intrusion vanishes completely on the theory of surface erosion prior to surface extrusion.

6. The features characteristic of the upper surfaces of sills—the occurrence of overlying beds or fragments thereof, aphanitic structures, included fragments in the upper part of the sheets—are not found.

7. The medium to coarse texture, which characterizes the sheets, would be found at the base of thick surface flows as well as in sills, being dependent not on the nature and thickness of the cover so much as on the rate of cooling.

8. A glassy matrix, amygdaloidal or porous structure, basaltic texture, flow structure, and associated volcanics would not be characteristic features of the under parts of surface flows, and the upper parts of these sheets are unquestionably removed, without a single exception.

BALANCING THE EVIDENCE

It seems that we have no data relative to the actual character of the upper surface of the trap sheets. Such negative evidence as is available is equally applicable to both theories. With regard to the texture of the residual basal portions of the sheets, there are no recorded differences which would indicate that it belonged to a flow and not to a sheet. On the other hand, numerous unconformities exist and the diabases are known to rest successively upon Laurentian, Kewatin, Huronian (possibly Middle and Lower, certainly Animikie), and Keweenawan, and these unconformities are very widely distributed. Owing to the mechanical difficulties involved by any other interpretation, it seems to the writer that the balance of evidence available is distinctly in favor of considering these capping sheets as the basal residuals of a once very extensive flow or series of flows of a very fluid diabase over the well dissected topography of a previous cycle.

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[7] It is recognized that this even upper surface is now an erosion surface and does not necessarily owe its even character to an original uniform structural surface.

Source and Nature of the Flows

Information about the source of the diabase is scant. No specific centers of eruption are known. Some of the sills in the sediments are found associated with dikes of similar rock. Instances where the actual connections between the two have been observed are rare, and the writer has never had the opportunity of studying one in detail. Two localities have been found where the writer thinks he has located a connection between a dike from below and the overlying diabase cap. In both instances only one side of the supposed dike in contact with the adjacent rock was found, though the connection with the sheet is distinct, and it can not be regarded as certain that the intrusive is a dike from below.

One of these lies east of the south end of Black Sturgeon lake, about 3 miles from the lake, near the head of a dry canyon cut in Kewatin schists. Near the head of this gorge, on the north side, the schists are found to *overlie* the diabase, an actual contact having been found. The contact occurs in the face of the cliff which forms the north wall of the canyon, and rises upward at an angle of about 20 degrees from the horizontal, the exposed portion being about 125 feet in length. This diabase, here lying *below* Kewatin schists, is directly connected with the main sheet of diabase that covers all that section of country south of lake Nipigon and extends eastward beyond the Nipigon river. If this is a feeding dike, the other contact lies farther east, beneath the diabase sheet, and would not now be accessible.

The second locality is near the head of Pine portage, on the Nipigon river, at the north end of the area of gneiss exposed in the gorge. Opposite the head of the portage are high bluffs of diabase, rising over 300 feet above the river. Near the summit we found a large mass of gneiss overlying the diabase, which forms the whole front of the cliff facing the portage. No actual contact could be found, though the two rocks were traced to within about 10 feet of each other. A small intervening hollow, filled with loose soil, obscures it. The contact seemed to dip away from the cliff face and stands approximately at an angle of 45 degrees, dipping toward the northeast. Since the gneiss here is part of the Archean ridge to the south, that has unquestionably been buried in a flow of diabase, it is possible that the preexisting topography was such as to bring about the relations here described without any intrusion from below in this locality.

A third locality of interest is at Camp Alexander. About one mile below the steamboat landing, at the mouth of Bass creek, on the west side of the river, a nearly vertical contact between diabase and granite occurs. Since the granite outcrops on the east side of the river, the width of the diabase mass is about 400 yards, or less than a quarter of a mile. A number of outcrops show that it extends northward for about 2 miles. At the north end, part of it is spread out over granite as a capping sheet. No conclusive evidence was found to show that the diabase at Camp Alexander and vicinity occurs as a dike. There is independent evidence to show that it occurs at the bottom of an old Archean valley and there is reason to suspect that the mass of diabase here preserved occupies a depression that was once a gorge in the valley floor.

Adjacent to the shores of lake Nipigon there are several localities where wide dikes of diabase similar to that in the sheets occur. There are also numerous outlying large and small masses of diabase on the summits of Archean ridges, on their sides, and in the valley bottoms. In many instances it was impossible to find any actual contacts. In quite a few cases, particularly where the diabase lies at the summit or on the side of a ridge, sufficient actual contacts were found to show that the remnants were parts of sheets. With regard to some large masses of diabase, very coarse in texture (in one instance we found olivines more than one inch across), no contacts were found. While the coarse texture suggests slow cooling, the mass may have cooled slowly, because it lay at the bottom of a hollow and was thus deeper below the surface than the portions of the sheet lying above the adjacent hills; or it may have been more closely associated with a feeding dike and been the last to cool and solidify. In the majority of cases the textures of the more or less isolated and outlying masses of diabase are neither coarser nor finer than the textures of the different parts of the sheets in the main area.

While it seems probable that the diabase flowed out over the area from many fissures, very few of these fissures are known. The numerous outlying masses and ridges of diabase, scattered everywhere over the Archean, to the north and northeast of the main area close to the bed of the present lake Nipigon, are often supposed to be remnants of an extensive system of dikes. Detailed examinations of many of them have shown that, so far as accessible contacts are concerned, they are probably parts of sheets. Of course nothing is positively known about their cores, but one is justified in assuming uniformity on the Archean topography. In many cases, between the detached remnants of sheets or between these remnants and the main mass of diabase, are wide dikes now unconnected with any sheets, but of similar rock. These dikes probably mark some of the channels through which the molten diabase ascended.

The diabases are so widespread that we must infer that they were intruded at many different points, either simultaneously or successively. While only a few possible points of intrusion are known, we can infer the existence of others. Still it must not be forgotten that in the Snake River fields flows of between 50 and 60 miles are recorded for lavas which solidified into basalt. Where the lava was fluid (as is indicated by the coarse crystalline structure and absence of flow structure) and remained quiescent for a long time subsequent to extrusion, and where the outflow was so great that even the small remnants of the sheets now left show a minimum thickness of over 600 feet for a belt more than 60 miles in length—under such conditions, very few openings would suffice.

CHARACTER OF THE PREEXISTING TOPOGRAPHY AND DATE OF DENUDATION

Previous to the extravasation of the diabase the section of country lying south of the present lake Nipigon was underlain largely by Keweenawan sedimentary rocks, with here and there exposures of older crystallines. In the basin of lake Nipigon and northward there were numerous sedimentary remnants, outliers upon the Archean. The Archean itself presented that undulating and mammillated topography so characteristic everywhere along the margin between the sedimentaries and the earlier rocks.

In fact, the topography was that of a belted coastal plain with the Archean oldland to the northeast with numerous sedimentary outliers in the basin of lake Nipigon. The southwest part of the present basin represents a portion of the inner lowland. The main area of sediments lay south and southwest of the lake, and the first cuesta, that facing the oldland, can be traced from near the Canadian Pacific Railway line, lying to the west of the present Black Sturgeon valley, and continuing northwest to a point about 20 miles southwest of Nipigon House, where it turns southwestward again. The present Black Sturgeon river runs along the lowland in front of the cuesta to within a few miles of the present Canadian Pacific Railway bridge, where it turns and enters the cuesta, crossing to lake Superior through a gorge similar to that of a consequent stream.

The ancient belted coastal plain of North America, so well and characteristically developed nearly continuously around the whole convex southern, southwestern, and western border of the Archean oldland, is usually considered to be of post-Cretaceous age, it being inferred that the dissection by which the belted features of the topography were developed took place subsequent to that long period of post-Paleozoic planation which continued to the close of the Cretaceous.

As the Nipigon belted coastal plain—only a mere remnant clinging to the edge of the Laurentian peneplain, it is true—lies midway between the coastal plain of the Great lakes of the Saint Lawrence system and the similar coastal plain of the Mackenzie and Saskatchewan river systems, it seems not unreasonable to suppose that the conditions which were so uniform and similar on all sides of this area (for a similar belted coastal plain seems also to have developed north of the Archean oldland in the Hudson Bay basin) should have also prevailed here, and that the Nipigon coastal plain remnant may also be of post-Cretaceous age.

The incursion of diabase, judging by the nature of the contacts and from the character of the pre-diabase dissection and relief, took place at a time when the relief was at its maximum development. Numerous outliers lay in front of the main cuesta on the newly uncovered lowland, and remnants of many of these outliers are still preserved as lava-capped mesas standing well out on the lowland or even on the oldland. Had it not been for the protecting lava cover, it is very probable, in view of the enormous amount of erosion that has certainly taken place since the advent of the diabase, that the number and area of these outliers would be much less. In fact, it is quite possible that little, if any, of the Keweenawan sediments would have been preserved north of lake Superior.

Distribution of the Diabase

The main sheet of diabase occupies the ancient lowland depression of the Nipigon coastal plain, and roughly forms a crescentic mass bounding lake Nipigon on the south, southwest, and west. With small gaps where subsequent dissection has curved deep valleys,[8] in the bottoms of which the earlier rocks are exposed, it extends in a crescent form from Gull lake on the east to beyond the Wabinosh river on the west. Southward and southwestward remnants of the sheet form mesa caps on many of the prominent ridges found scattered widely over the area on which the main mass of the sediments is still preserved, between lake Nipigon and lake Superior. Northward, practically the whole of the basin of the present lake Nipigon is underlain by diabase, and beyond the lake as far as the Hudson Bay divide, mesas occur. Northeast of the lake the principal remnants of the main sheet forms the north and south peninsulas of Ombabika, and another large area, possibly a part of this sheet, occurs 12 miles farther northeast, at Grass lake. Since the oldland gradually increases in elevation northeastward, it is doubtful if the northeast edge of the sheet extended many miles beyond Grass lake.

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[8] Pijitawabikong bay, Nipigon River gorge, Black Sturgeon passage, and several minor passages.

At the south end of Pijitawabikong bay the remnant of the sheet is at least 600 feet thick. Near the middle of the crescentiform main mass of diabase, at Tchiatang bluff, on Black Sturgeon bay, it is at least 650 feet from base to summit. The remnant at Inner Barn island, in Wabinosh bay, is 600 feet thick. In all these localities and in numerous other places not here indicated specifically a careful examination was made of the sheet from base to summit, and, apart from the fact that at some points erosion has developed great benches, no noticeable change in the holocrystalline texture of the rock was observed and no indication was found that would lead one to think that the sheet consisted of successive flows.

At the northeast angle of lake Nipigon, on the peninsula of Ombabika, and at Livingstone point the thickness of the remnant of the sheet is about 300 feet, thinning to about 250 feet where masses of sediments underlie it. At various points around the margin of the oldland, remnants on the adjacent uplands vary in thickness from 12 feet in one noted instance to 150 feet. With regard to the masses of trap capping blocks of sediments on the cuesta to the southwest of the lowland, unless there is specific evidence to the contrary, it can not always be decided whether they are remnants of an original capping sheet or are parts of a sheet that had been intruded between sedimentary beds, the overlying beds and the upper parts of the sheet having since been removed by erosion.

The relations of the thinner capping sheets around the lake basin on all sides of the lowland to the main mass in the lowland can be well comprehended by inferring that the molten diabase probably filled the lowland basin to overflowing and then spread out on the adjacent higher ground on all sides. Undoubtedly some of the diabase came to the surface through fissures on the margin, but not within the basin, but the tendency would be for it to move toward the lower ground. Eventually the diabase from its several sources probably filled the whole basin and spread far out on the adjacent uplands on all sides.

As to the maximum depth of the molten diabase over the lowest parts of the flooded lowland, no accurate figures can be given. An approximation based on the thickness of the remnants in the basin and of some outside it, but immediately adjacent on the neighboring upland, would place it at a minimum thickness of more than 1,000 feet.

Summary of the post-Cretaceous geologic History[9]

Following the period of elevation which succeeded the Cretaceous peneplanation epoch, a belted coastal plain topography had reached a mature stage of development in the lake Nipigon basin. There were still many remnants of the lower members of the coastal plain sediments, scattered over the main lowland between the Archean oldland and the (probably) paleozoic sediments. At a number of different points in this and in the adjacent areas, huge masses of molten diabase were forced upward from below through fissures. In those parts of the district where the cover of Paleozoic sediments was not removed the diabase was forced between many of the beds in laccolitic masses or broke across the beds as dikes. Near the edge of the cuesta some of the laccolitic masses probably forced their way (horizontally) to the edge of the escarpment and the molten diabase poured down upon the lowland. Through other fissures passing only through the Archean rocks of the lowland, fluid diabase was also forced upward. The flows followed each other with sufficient regularity and so closely that a large amount of liquid rock collected in the lowland basin in front of the inner cuesta, between it and the oldland, eventually reaching such a height that it overflowed upon the adjacent uplands. Owing to its depth, the rock cooled very slowly except in the lower basal portions and in the upper part. Probably the middle portions congealed nearly simultaneously throughout the whole mass, after a long period of slow cooling.

Subsequent erosion has removed over 90 per cent of the diabase (possibly 95 per cent) and a considerable portion of the underlying sediments. Here and there, however, portions of the fossil post-Cretaceous coastal plain have been preserved by its diabase cover. The post-diabase degradation has developed a type of topography very similar to that of the original coastal plain. Subsequent to the outpouring of the diabase a system of block faulting has slightly affected the region, disconnecting contiguous portions of the diabase sheets and sills, modifying locally the type of topography developed, and differentially affecting the rates of erosion in different parts. The presence of laccolitic sills and capping sheets of diabase, much harder and more compact than the underlying sediments, has resulted in the development of the numerous mesas and buttes so characteristic of the region.

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[9] Post-Cretaceous on the assumption that the Great Lake basins (except Superior) are of this date.

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CONTRIBUTION TO THE GEOLOGY OF THE SILVER PEAK QUADRANGLE, NEVADA[1]

BY H. W. TURNER

(Presented before the Cordilleran Section of the Society December 31, 1908)

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[1] Published by permission of the Director of the U. S. Geological Survey. Manuscript received by the Secretary of the Society January 13, 1909.

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INTRODUCTION

The following notes, based on field work done in 1899 and 1900, were obtained while making a detailed geological map of the Silver Peak quadrangle for the U. S. Geological Survey. I was assisted in this work by C. E. Knecht, of Stanford University. A paper was published in 1900[2] on the Tertiary lake beds (Esmeralda formation), and a short summary concerning the sedimentary formations in general of Esmeralda county was published in 1902.[3]

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[2] American Geologist, vol. xxv, 1900, pp. 168-170; Twenty-first Annual Report of the Director of the U. S. Geological Survey, 1900.

[3] American Geologist, vol. xxix, 1902, pp. 261-272.

The complete description of the formations and rocks shown on the detailed geological map was sent to Washington, and this was used by J. E. Spurr in his paper,[4] "Ore deposits of the Silver Peak quadrangle." A generalized geological map, taken from my detailed map, was publishea

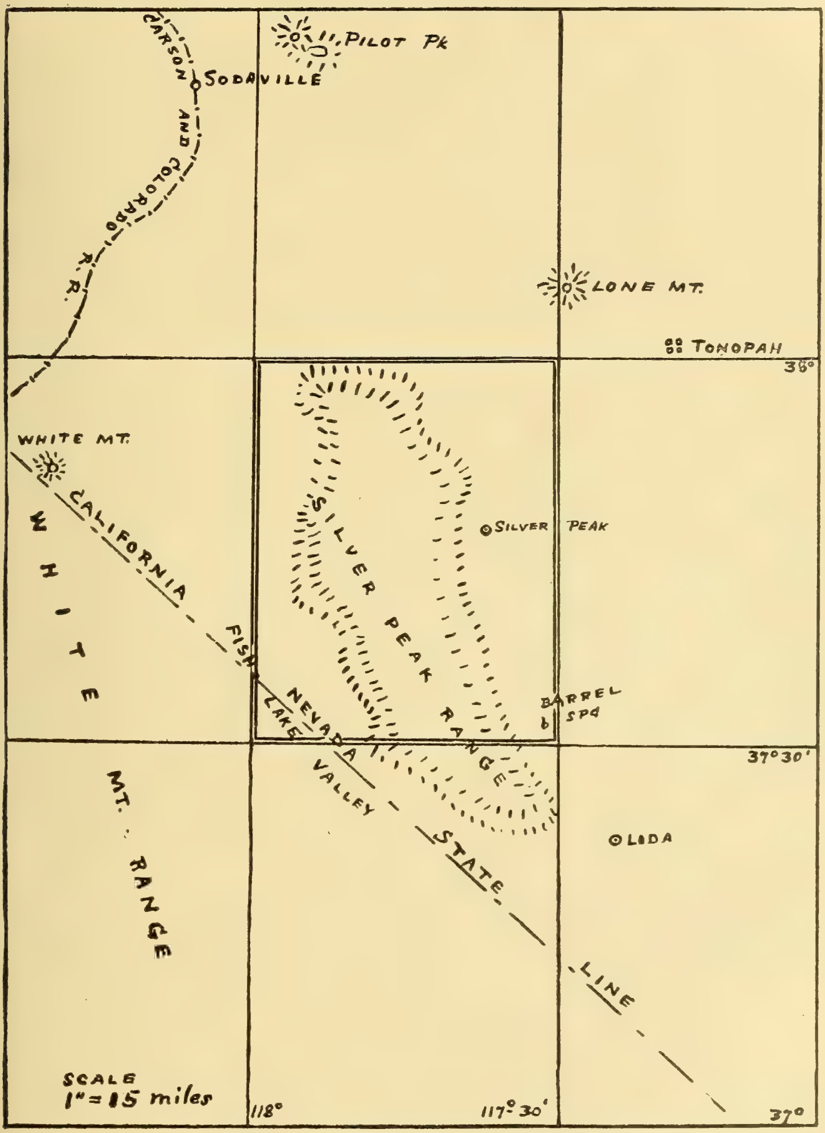
CARSON AND COLORADO R.R.
SODAVILLE
PILOT Pk
LONE MT.
TONOPAH
38°
WHITE MT.
WHITE MT. RANGE
CALIFORNIA
FISH LAKE VALLEY
NEVADA STATE LINE
SILVER PEAK RANGE
SILVER PEAK
BARREL SPG
37°30'
OLIDA
SCALE
1" = 15 miles
118°
117° 30'
37°

FIGURE 1.—*Map of the Vicinity of Silver Peak Range*

by Mr Spurr, and this map may assist the reader of the present paper in getting an idea of the geology of this interesting region. Many Cambrian fossils were collected, mostly in an excellent state of preservation, which, with others obtained later by F. B. Weeks, probably will be made the basis of future publications by the U. S. Geological Survey.

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[4] Professional paper no. 55, U. S. Geological Survey, 1906.

On his generalized geological map the rocks here included under "pre-Cambrian complex" are called by Spurr "Intrusive granitic rocks complexly injecting Paleozoic strata." This, however, is misleading, inasmuch as the complex is composed largely of gneisses and schists which were probably made gneissic and schistose before the Cambrian was laid down, and in that case would not be intrusive in the Cambrian. However, the white granite and pegmatite associated with these ancient gneisses are intrusive to some extent in the basal green schists, quartzite, and dolomite which underlie the fossiliferous Cambrian rocks. As this white granite is intimately associated with the pre-Cambrian, it was mapped and described as a part of the pre-Cambrian complex, although evidently later in age than the bulk of the gneisses and schists which are intruded by it. This latter granite (alaskite of Spurr) and pegmatite was nowhere seen intruded in fossiliferous Cambrian rocks.

The evidence of the continuity of sedimentation from the Upper Cambrian into the graptolite beds of the Ordovician appears to be quite plain in one section near Emigrant pass, at the north end of the Silver Peak range. Further collections from this section should bring forth interesting data. There is probably no field in Nevada where there are better exposures of the older Paleozoic series, and the region merits fuller investigation.

Geographic Features

EXTENT AND TOPOGRAPHY OF THE QUADRANGLE

The Silver Peak quadrangle comprises a portion of the Great basin lying immediately east of the Inyo mountains. It is thus in the western part of the Basin region. It is limited by the parallels of 37° 30′ and 38° north latitude and by the meridians 117° 30′ and 118° west longitude. The larger portion of the area lies in Esmeralda county, Nevada, but the extreme southwest corner is in Mono county, California. There are portions of several mountain groups represented in the quadrangle, including nearly all of the Silver Peak range. In the northeast corner are the foothills of Lone mountain; along the east border are the foothills of the Montezuma mountains; near the southeast border the Palmetto mountains, and the hills in the extreme southwest corner belong to the

Inyo range. Occupying the depressions between these groups of mountains are extensive valleys, that between the north end of the Silver Peak range and Lone mountain being known as Big Smoky valley, that between the Silver Peak range and Montezuma mountains as Clayton valley, and that on the west, between the Silver Peak range and the Inyo range, as Fish Lake valley. The lowest portions of each of these valleys form playas, covered with an incrustation of various salts, white in color, rendering them a conspicuous feature in the landscape.

The ranges are nearly all quite complex in character. None of them can be said to represent the typical Basin Range structure. However, the steep slopes of several of them are clearly the result of uplifts along normal faults. To this extent the Basin Range structure may be said to be represented. The details of these structure features will be given under a separate heading.

DRAINAGE

The drainage system consists of waterways, or "washes," which radiate from the ridges toward the valleys. These waterways are ravines and canyons of the ordinary Basin type. On the slopes between the edge of the mountain ridges and the lowest points of the valleys the "washes" are cut chiefly through the older alluvial fans and through Tertiary lake beds. In such cases the banks are commonly precipitous, with a maximum height of about 250 feet. There is usually a flat bottom to such washes, up which one may drive with a light vehicle for long distances. As previously stated, none of these "washes" contains any permanent stream, with the exception of a single ravine hereafter noted. Even after rains the running water in the "washes" seldom reaches the playas of the valleys, and the thin sheets of water covering these playas after rains represent chiefly the material which has fallen on the playas themselves or on their margin. An exception to this is Fish Lake valley, where floods from the Inyo range frequently spread out over the valley. Nearly all the precipitation within the quadrangle either sinks immediately into the ground or is carried down on to the detrital slopes and there disappears, while that in the playas is gradually evaporated.

WATER SUPPLY

Within the limits of the quadrangle, except after rains, there is no running water whatever except the stream, less than a mile in length, which issues from the Jeff Davis spring, on the east slope of Silver Peak range. If it were not for the occasional springs scattered over the quadrangle and the possibility of getting water by sinking wells, the region would be practically uninhabited. Some of the springs, however, supply an abundance of good drinking water, while others contain so much alkali as not to be of value for domestic use. Near Silver Peak there is a hot spring with a temperature of 132° Fahrenheit (November, 1900), containing a large amount of chloride of sodium, while a few feet away is a cool spring. The best available water in the district comes from springs along the summit of the Silver Peak range to the west and south of Red mountain and along the north base of the Palmetto mountains. At Silver Peak there is a pond in which there is water standing the year round, and another, known as Fish lake, may be seen in Fish Lake valley.

PRECIPITATION

No systematic records for any great length of time have been kept within the limits of the quadrangle, but the records at Hawthorne, Sodaville, and Palmetto, all points in Esmeralda county, indicate that the average annual precipitation varies from 3 and 5-10 inches in the valleys to 15 inches on the highest ridges. It frequently rains or snows on the mountain tops when the neighboring valleys receive no precipitation whatever.

SCENERY

Except on the higher ridges and about some of the marshes, the vegetation of the region ordinarily presents a gray effect; but the general somber tints are relieved at some points by the varied and sometimes even brilliant colors shown by the rocks. The ridges being usually devoid of soil, the colors of the rocks are conspicuous. The Cambrian rocks are dark limestones, buff marbles, green quartzites, schists, and slates. The Ordovician rocks are usually black siliceous argillites and gray and red slates. The Tertiary lake beds are chiefly light buff shales, tawny sandstones, and tern gray marls. By far the most brilliant colors are those of the volcanic rocks. The basalts and basic andesites are usually dark brown or black, but the rhyolites exhibit great diversity. In a little group of rhyolite hills may be noted buttes of dark brown rhyolite—the color in this case being mostly the effect of surface weathering—slopes of cream and pink tuffs, and little hillocks of a bright brick red. This is particularly true of the north portion of the Silver Peak range, the north face of which exhibits a series of horizontally bedded rhyolite tuffs and breccias of diverse colors (figure 2, plate 9). At other points the rhyolite is of a green color. A chemical examination of this rock by Doctor Hillebrand showed that the green coloring material is probably an iron silicate. It does not contain chromium.

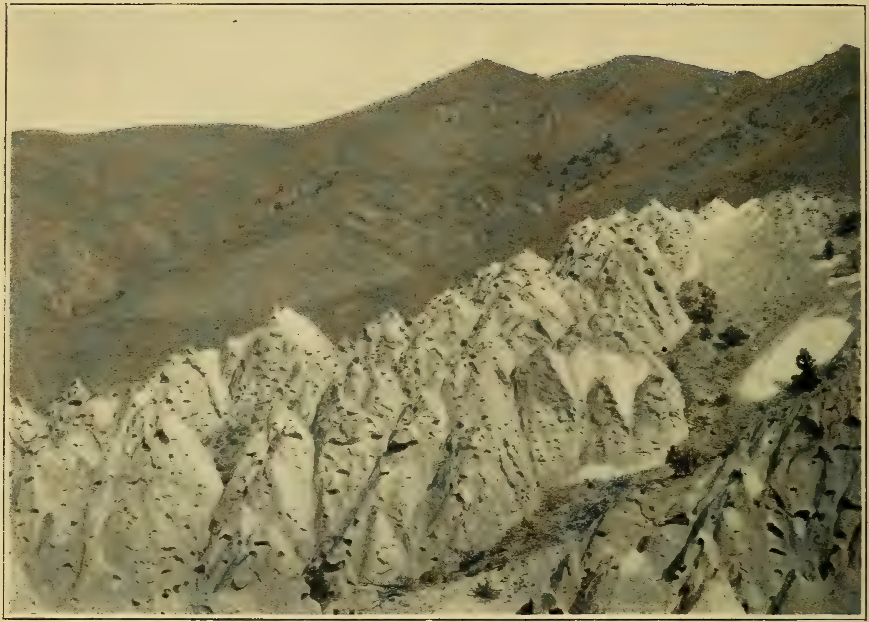

FIGURE 1.—RHYOLITE-TUFF, WEATHERED INTO GROUPS OF CONES

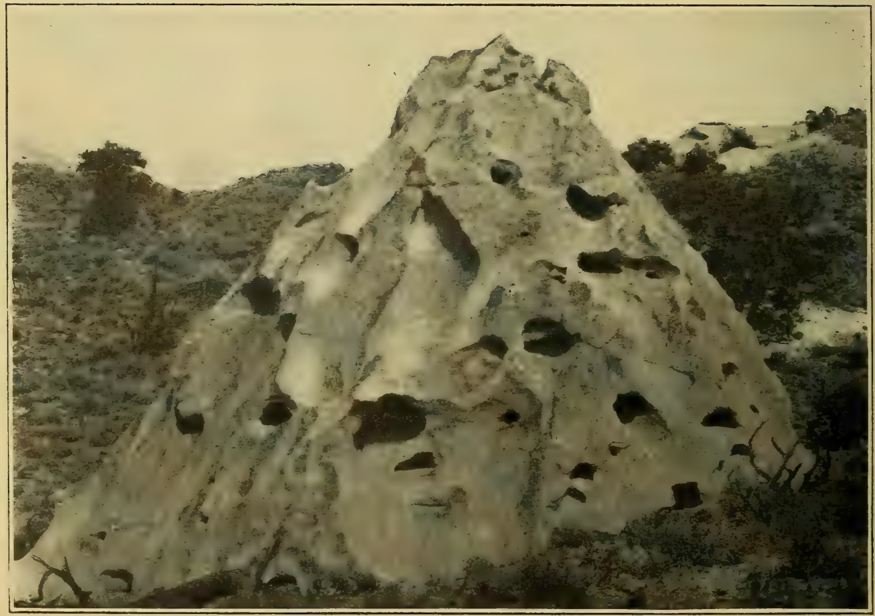

FIGURE 2.—SINGLE WHITE CONE 20 FEET IN HEIGHT

RHYOLITE-TUFF AND SINGLE CONE

The rhyolite tuffs often weather in curious forms. Figure 1, plate 6, represents a group of little white cones at the northwest base of the Palmetto mountains, in the little cavities of which small rodents make their nests; figure 2, plate 6, shows a single one of these cones, which is perhaps 20 feet in height.

DESERT VARNISH

On the detrital slopes many of the boulders of lava and other rocks are covered with a dark brown shining coating, known as desert varnish. Some of this material was examined by Dr H. N. Stokes, who found it to be chiefly manganese dioxide. Under this outer coating in the basalt boulder examined, there is a decomposed layer in which Doctor Stokes determined the presence of a silicate soluble in hydrochloric acid and containing alumina and lime. This silicate is not feldspar, since it is soluble in acid. Oscar Loew[5] regards the desert varnish of the Mojave desert as having been deposited on the rocks as carbonate of manganese by the retreating waters of a shallow ocean which he supposes once covered that desert. The binoxide of manganese was then formed from the carbonate by the action of sunlight and air. Doctor Loew placed a granite boulder weighing 80 grams in hydrochloric acid until it showed its natural color. The material in solution in the acid was as follows:

	Grams
Sesquioxide of iron	0.078
Binoxide of manganese	0.038
Oxide of nickel	trace

Dr G. P. Merrill[6] investigated the desert varnish on pebbles of quartzite in Toole valley, Utah, which was formerly covered with the waters of lake Bonneville. He found that the coating gave reactions for iron and manganese. He writes:

> "It is evident that the exterior coloring of the desert varnish is due mainly to a local segregation of oxide of iron with a little manganese and organic matter. All things considered, it seems safe to assume that this local discoloration is due to a superficial segregation of the metallic contents of the quartzite in a state of higher oxidation, the iron originally in the form of a carbonate being converted into a hydrated oxide, while the lime carbonate itself was removed in solution. The small amount of organic matter may have been added from external sources from the water of the original lake."

There is no evidence that the detrital slope in Clayton valley from which the specimen of desert varnish examined by Doctor Stokes was collected was ever covered with standing water. Nevertheless, Merrill's hypothesis, that the desert varnish is due to a local segregation of the metallic contents of the rocks on which it occurs, seems to best account for the varnish. It is found only on the upper exposed surfaces and on slopes that have been exposed to the elements for a long period, not being observable on the boulders of the newer washes and alluvial fans.

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[5] Wheeler Survey; Annual Report for 1876, Appendix JJ, p. 179.

[6] Bulletin no. 150, U. S. Geological Survey, pp. 389-391.

PRE-CAMBRIAN COMPLEX

LOCATION AND COMPOSITION OF THE COMPLEX

Within the limits of the quadrangle, there are two areas which are regarded as pre-Cambrian in age. One of these forms the larger part of Mineral ridge, west of Silver Peak village, and the other, a small area, lies 5 miles northeast of B. M. 4996, in the northeast part of the quadrangle and just west of an area of the basal dolomite. This dolomite is placed for convenience with the Lower Cambrian. These areas seem to represent the oldest rocks of the district, and this complex distinctly underlies the Lower Cambrian beds.

The complex is composed of granite-gneiss, quartz-monzonite-gneiss, granite-augen-schists, calcareous augen-schists, and small lenses of hydrous mica-schists.

THE GNEISSES

The gneisses vary in composition. Some of them are true granite-gneisses, in which the feldspar is chiefly orthoclase, and such gneisses usually contain muscovite or white mica often with some biotite. A second kind may be called quartz-monzonite-gneiss or a granodiorite-gneiss, since it contains both orthoclase and plagioclase in approximately equal amounts, and in this type the predominating mica is biotite.

A partial analysis of one of the quartz-monzonite-gneisses (number 224) by George Steiger gives the following results:

Silica	69.34
Lime	2.35
Soda	4.51
Potash	3.19

At some points where these two gneisses occur together, there seems to be evidence that one is intrusive in the other, but the evidence as to the relative age of the two is not consistent at different points, the granite-gneiss apparently being older at one locality and the quartz-monzonite-gneiss at another. Other gneisses, similar in general appearance to the above, contain chiefly plagioclase, thus forming a quartz-

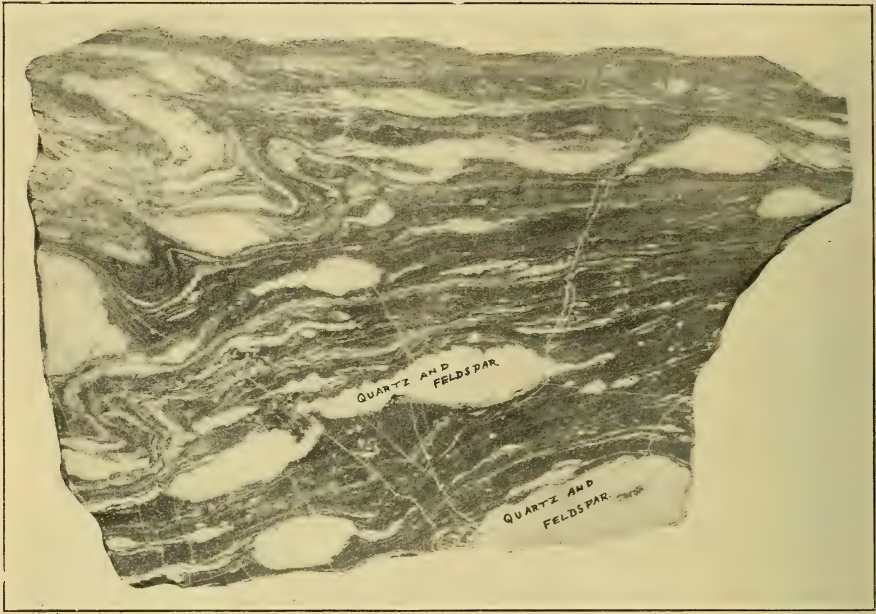
QUARTZ AND FELDSPAR
QUARTZ AND FELDSPAR

FIGURE 1.—CALCAREOUS AUGEN-SCHIST

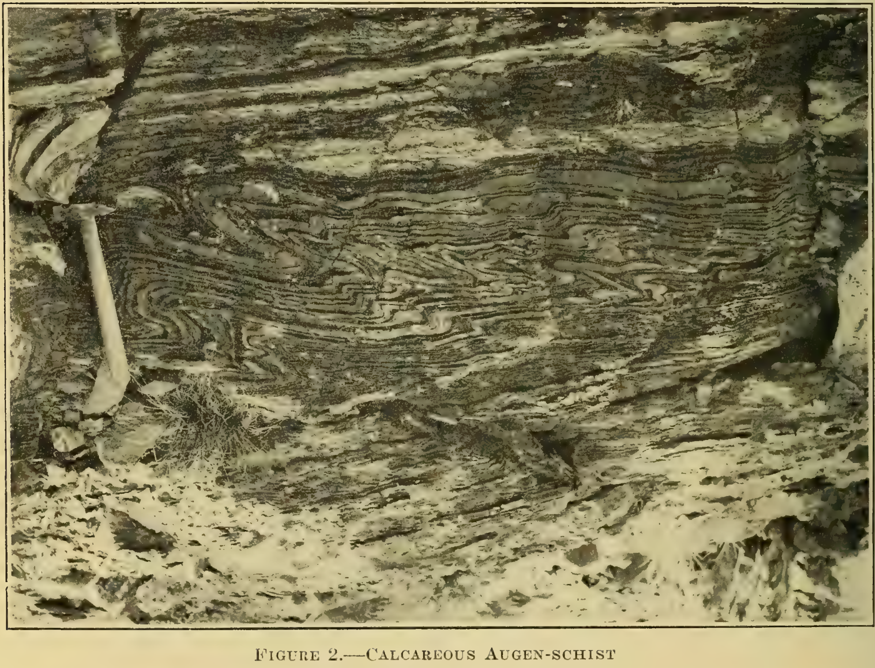

FIGURE 2.—CALCAREOUS AUGEN-SCHIST

CALCAREOUS AUGEN-SCHIST

diorite-gneiss. When any two of these gneisses are in contact the gneissic structure of the one is found to be parallel to that of the other.

THE SCHISTS

The schists always appear to overlie the gneisses. They are of two kinds. One has the composition of a granite and shows under the microscope strong evidence of shearing, the feldspar and quartz grains being crushed and faulted and largely reduced to minute granules. In this schistose granulated groundmass large grains of quartz, feldspar, and muscovite form kernels or augen, around which the lines of granules and the lines of muscovite of presumably secondary origin curve. Such a rock may be designated a *granite-augen-schist.* The other type of schist weathers a brown color, strongly resembling sedimentary limestone. It often contains streaks and augen of the white granite, as shown by figure 2, plate 7. On a large scale the same thing may be seen at many points, but nowhere better than in the ravine which leads up to the Great Gulch mine, where the streaks of granite are often several inches in diameter, producing the impression of intrusive sheets in the darker schist. The rocks are here greatly plicated, and as the streaks of granite are involved in this plication, it is evident that the plication occurred after the intrusion. Some of the more massive occurrences of this type of schist show no augen to the unaided eye. At the west base of the ridge of Lower Cambrian rocks, with an altitude of 8,400 feet, which lies about 3 miles north of Red mountain, immediately underlying the Lower Cambrian limestone, are certain dark rocks resembling slates, in which are dikelike streaks of the coarse white granite at one or two points. These slate-like rocks were at first supposed to be a part of the Cambrian series, but the microscope shows them to be of essentially the same composition as the schists above described, and hence they are mapped as a part of the complex. While these schists vary in macroscopic appearance, under the microscope these differences are less striking. The fine grained schists and slaty rocks are found to always contain grains or augen of feldspar or quartz, or both, and often of secondary minerals, including an epidote-like mineral, in a groundmass of minute grains of carbonate of lime. The fine grained portions of the coarser calcareous augen-schists, represented by figure 1, plate 7, are an exact facsimile in some cases, as seen under the microscope, of the fine grained schists, which, when massive, so strongly resemble sedimentary limestone on exposed surfaces (see figure 2, plate 7).

Nearly all of the thin-sections show evidence of strong shearing or mashing, the original grains being thoroughly crushed and arranged in parallel streaks. Such of the grains as have not been granulated are fractured and rounded and the quartzes usually show undulous extinction. Lines of mica foils, chiefly finely divided muscovite, contribute greatly to the formation of the schistose structure. While the two types of schists here described are very different in chemical composition—the granite-augen-schist having the composition of granite or of arkose, and the lime-rich extreme of the calcareous augen-schists the composition of an impure limestone—at numerous points schists representing transitions from one to the other may be found. Such a series, all taken from one bluff about 1 mile southeast of North spring, shows transitions from a typical granite-augen-schist composed of lines of minute grains of quartz and feldspar and of minute muscovite foils in which are imbedded large grains of feldspar and quartz and muscovite foils with little or no carbonate to a granite-augen-schist similar to that just described, but with lines of carbonate granules in addition. The calcareous augen-schists may represent thin bedded limestone and lime shales thoroughly injected and infiltrated with granitic material.

Analyses of calcareous Augen-Schists and of Granite-Augen-Schists

George Steiger, Analyst

	Number 787	Number 736.	Number 744.	Number 733.	Number 734.
SiO_2	22.45	30.31	62.59	71.48	73.46
CaO	34.46	29.35	5.00	1.50	1.38
Na_2O	.54	.86	3.76	3.35	4.26
K_2O	1.87	2.15	2.07	3.85	2.80
CO_2	23.13	21.51	3.20	1.03	.23

Numbers 787 and 736 are of the type designated calcareous augen-schists, and numbers 744, 733, and 734 are typical granite-augen-schists.

THE WHITE GRANITE

The white granite (alaskite of Spurr) was nowhere observed certainly intrusive in fossiliferous Cambrian or later sediments. It is usually a coarse grained rock, composed of orthoclase or potash-feldspar, with some albite or soda-feldspar and frequently some muscovite, but it is often nearly destitute of black mica. By the loss of quartz it grades over into syenite. There is sometimes plagioclase present. The following partial analyses of white granite (alaskite) by George Steiger indicate the chemical composition:

Analyses of the White Granite (Alaskite)

	Number 467.	Number 259.	Number 210.
Silica	70.80	72.72	73.59
Lime	2.71[7]	.51	.49
Soda	3.95	1.65	3.62
Potash	3.83	6.93	4.13

Granite number 467 is from 6.3 kilometers west of north from Red mountain. Collected at the edge of an included mass of marble. Dikes of this rock are in the dolomitic marble. Macroscopically, a coarse grained nearly white rock, apparently composed chiefly of feldspar. Microscopically, an even grained rock composed of feldspar, quartz, and muscovite. The feldspar is microcline and plagioclase. There are present minute zircons. Carbonate of lime is rather abundant in cracks and between the grains of the primary constituents, which are fresh. The rock shows evidence of crushing. The quartz is in interlocking, in part elongated, grains showing undulous extinction.

Granite number 259 is from the lower tunnel of the Mary mine. Macroscopically, it is a light gray granite showing white feldspar, quartz, and biotite. Microscopically, it is composed of microcline and orthaclase, quartz, oligoclase, biotite, muscovite, zircon, and apatite. There is a little carbonate and chlorite present. The rock shows no evidence of crushing or shearing.

Granite-gneiss number 210 is from a dike in quartz-schist 1.5 kilometers northwest of the Silver Peak benchmark. This quartz-schist underlies the lower Cambrian. Macroscopically, it is a white gneissic granite containing muscovite. It is evidently a sheared form of white granite. Microscopically, it is composed of orthoclase, albite, quartz, plagioclase, and muscovite. One minute garnet was noted. The rock has been strongly sheared, the feldspars and quartzes being fractured and granulated. It is now a granite-gneiss.

Some of the pegmatite dikes seem to be genetically related to the white granite, and these dikes are very clearly later than the gneisses, for they cut across the gneissic banding.

The high cliff which forms the west wall of the deep north-south canyon that lies about 1½ miles northwest of the New York canyon is formed from top to bottom of alternating lenses of the white granite and augen-schist. These lenses or layers lie nearly horizontally. If we suppose the lenses of white granite to be intrusive sheets in the augen-schists, their lens-character and their lack of continuity may be regarded as due to pressure exerted after the intrusion.

The gneissic and schistose structures of the pre-Cambrian gneisses and schists above described are usually roughly parallel with the bedding of the overlying Cambrian sediments. Where the Cambrian rocks have been disturbed, the pre-Cambrian rocks have likewise been disturbed; where they lie nearly horizontally, the same is true of the underlying rocks.

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[7] The high content of lime in this specimen is plainly due to carbonate of lime infiltrated into cracks, as shown by the microscope. The rock is fresh and a true granite.

The crushing and recrystallization of the rocks of the pre-Cambrian appears thus to have been effected without tilting or folding, and presumably occurred before the deposition of the Lower Cambrian sediments, for in these there is little evidence of a schistose structure or of recrystallization, the slates or shales often containing recognizable Olenellus and other fossils not far from the contact of the pre-Cambrian with the Cambrian. This would likewise suggest that the white granite involved with the augen-gneisses is older than the Cambrian, as otherwise its intrusion would have produced contact metamorphic effects on the Cambrian sediments, and that the dikes of white granite which at some points intrude the basal dolomitic rocks are of later origin than the gneisses of the complex and of the same age as the coarse pegmatite dikes, from which they differ but little in chemical composition. How horizontal gneissic and schistose structures may be produced is difficult to explain, but probably they developed under a great superincumbent mass of beds now eroded. Much finer examples of flat lying gneisses are described by Dr Frank D. Adams[8] in Canada. This area of gneisses is referred by Doctor Adams to the Grenville series. In these gneisses are interpolated occasional bands of crystalline limestone and of quartzite. Over an area of at least 750 square miles the gneisses lie quite flat, or at most dip at an angle of 30 degrees. In one of the illustrations in Doctor Adams' paper (plate III, p. 13-*j*) a bluff of these horizontal gneisses is depicted which might readily be mistaken for undisturbed sedimentary rocks at a little distance.

Dr George M. Dawson,[9] in his presidential address before the Geological Society of America, in describing the Shuswap series of the Rocky mountains in Canada, indicates a relation between the Archean and Cambrian similar to that above described on Mineral ridge. He writes:

> "A distinct tendency to parallelism of the strata of foliation with adjacent borders of the Cambrian system has, moreover, also been noted in a number of cases. This might imply that the foliation was largely produced at a time later than the Cambrian, but the materials of some of the Cambrian rocks show that the Shuswap series must have fully assumed their crystalline character before the Cambrian period, and there are other evidences of their extensive pre-Cambrian erosion. It seems, therefore, probable that the foliation of the

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[8] Geological Survey of Canada; Report of progress, 1895, vol. viii. Report by Frank D. Adams on the geology of a portion of the Laurentian area lying to the north of the island of Montreal, pp. 11-*j*.

[9] Bull. Geol. Soc. Am., vol. 12, 1901, pp. 57-92.

Shuswap rocks may have been produced rather beneath the mere weight of superincumbent strata than by pressure of a tangential character accompanied by folding, and that both these rocks and those of the Cambrian were at a later date folded together."

In the foregoing it has been implied that the gneissic and schistose structures of the pre-Cambrian of Mineral ridge were developed in pre-Cambrian time, and that the planes of these structures were approximately horizontal. On this hypothetical horizontal floor the Algonkian (if present) and Lower Cambrian sediments were deposited. These are in large part fine grained quartzite, limestone, and shale, suggesting quiet conditions. Basal conglomerates are wanting. It may be held that if the rocks described as pre-Cambrian are really so, distinct evidence of an unconformity with the overlying Lower Cambrian should be observable. This, however, loses weight when we consider that the Lower Cambrian sediments, chiefly shale and limestone, must have been laid down in quiet water and, as supposed, on a nearly horizontal floor. Under these conditions basal conglomerates would not readily form. Moreover, the proof of strong stresses having been applied to the pre-Cambrian complex resulting in thorough gneissic and schistose structures, while the overlying Cambrian shows no such evidence of stresses, certainly suggests a considerable difference in age.

An old eroded surface is usually an irregular surface, but on account of disturbances subsequent to Lower Cambrian time, and on account of the erosion of the larger part of this old eroded surface of the pre-Cambrian of Mineral ridge, no satisfactory evidence was obtained as to its contours. Lying on top of the pre-Cambrian of Mineral ridge are two ridges composed of Lower Cambrian sediments. The even line of contact of the pre-Cambrian with these Lower Cambrian beds suggests that the hypothetical old eroded surface is not very irregular.

GRANITIC QUARTZ-VEINS

In addition to ordinary quartz veins in the pre-Cambrian, there are other veins and bunches of quartz which appear to represent the acid extreme of granitic dikes. Such veins usually contain a little feldspar and white mica, while others to which a similar origin may be assigned contain none. Assays were made of the quartz from two of these veins and only one of them showed the presence of gold. No sulphides have been noted in them. The quartz has often a banded structure, due, as shown by the thin-sections, to crushing and subsequent recrystallization, the granules of quartz being drawn out in parallel lines, so that some specimens might be called quartz-gneiss. This granitic quartz is usually of a dull or bluish color, precisely like some of the quartz-augen in the white granite where it has undergone crushing. The dull color is probably due to the innumerable dots, visible only under the microscope in the thin-sections. These dots when examined with a high power are in part resolved into minute cavities containing one or more gas bubbles in a fluid, but most of the dots are indeterminable. One of the thin-sections examined showed plainly a crushing of the rock, the large quartzes being broken and faulted. Two specimens assayed for the precious metals by the Selby Smelting and Lead Company gave the following results:

	Gold in ounces.	Silver in ounces.
No. 493	0.03	0.13
No. 500	none	none

It should be stated that no mica or feldspar was observed in quartz vein number 493, which alone contains gold and silver.

The following detailed description of thin-sections of the assayed granitic quartz taken from two of these veins indicate their appearance under the microscope:

Specimen 493.—Locality: Mineral ridge, on the same spur as the Mary mine. Specimen was taken from the vein lying just east of and overlying the Crowning Glory ledge.

Macroscopically, a dull bluish white quartz showing irregular fractures. Microscopically, a quartz rock evidently composed originally of large quartzes with uniform orientation throughout, but these grains have been crushed and faulted. The lines of shearing cut the large quartz grains in various directions. Most of the quartzes show undulous extinction.

Specimen 500.—Locality: 7.5 kilometers east of Red mountain, on Mineral ridge. The vein is about one meter thick.

Macroscopically, a bluish quartz containing some feldspar and white mica and possessing a gneissic structure. Microscopically, a quartz-gneiss in which the grains dovetail and are often elongated in one direction, producing a gneissic banding. The quartzes are turbid, and this appears to be due to innumerable minute dots mostly arranged in parallel rows, but these rows cut the gneissic banding at an angle. This quartz must have undergone deformation either when consolidating or subsequently. The lines of dots were undoubtedly formed at the time of consolidation, and as these are not parallel to the gneissic banding, the inference may be drawn that the gneissic structure is due to stresses exerted after consolidation. At one point there are phenocrysts of feldspar which show narrow lamellar twins with small extinction angle on the trace of the twinning plane. The index of refraction of this feldspar is greater than that of the balsam. It is probably oligoclase.

Many instances have been recorded of veins or dikes of quartz similar to those above described. Lehmann[10] has found them in Germany,

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[10] Lehmann: Untersuchung ueber die Entstehung die altkrystal-linischen Schiefergesteine. Bonn, 1884.

Hussak[11] in Brazil, and Crosby and Fuller,[12] Williams,[13] Van Hise,[14] and others in the United States, and J. E. Spurr[15] in Alaska. According to Hussak, the granitic quartz veins in certain instances build narrow contact zones in the slates which they intrude. Such zones would not be very noticeable, except when the veins or dikes are in rocks rich in alumina or lime which readily recrystallize into alumina and lime silicates.

DIORITE DIKES

In addition to dikes of the white granite (alaskite), there are numerous dark green dikes, usually less than 10 feet in width, but of much greater longitudinal dimensions. These will be referred to in general as diorite dikes, although some of them contain too little feldspar to be properly designated by that name. They are composed of green hornblende and plagioclase (andesine and labradorite), with accessory apatite, ilmenite, and other minerals, together with secondary products, such as epidote, chlorite, and carbonate of lime. At some points these diorite dikes grade over into hornblendite by loss of feldspar. For ordinary purposes they may be called greenstone. These dikes are evidently later than all the other rocks of the complex, for they cut across the gneissic and schistose structures, and frequently show at the border a fine grained layer or *salband,* due to the more rapid cooling of the intrusive magma where in contact with the wall rocks. These salbands are to be noted where the dikes are in contact with the white granite and the quartz veins, and hence later than these rocks. The following analyses are of two of the more basic dikes, neither of these being true diorites:

Analyses of Greenstone dioritic Dikes from Mineral Ridge

George Steiger, Analyst

	Number 208.	Number 222.
Silica	48.67	46.28
Magnesia	8.75	19.54
Lime	8.58	9.91
Soda	3.39	2.21
Potash	.99	1.89

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[11] Hussak: Zeits. für Praktische Geologie, 1898, p. 356.

[12] Crosby and Fuller: American Geologist, vol. xix, 1897, pp. 156-173.

[13] G. H. Williams: Origin of Maryland pegmatites. Fifteenth Annual Report of the U. S. Geological Survey, p. 679.

[14] C. R. Van Hise: Principles of the North American pre-Cambrian geology. Sixteenth Annual Report of the U. S. Geological Survey, part i, 1896, p. 688. Prof. Van Hise also treats of this subject in his fine monograph on metamorphism.

[15] J. E. Spurr: Geology of the Yukon district, Alaska. Eighteenth Annual Report of the Geological Survey, part iii, 1898, pp. 101-392.

The notes on granitic quartz veins presented here were enlarged on by J. E. Spurr in Professional Paper of the U. S. Geological Survey, no. 55, and many additional data presented.

Number 208 is from 1.1 kilometers northwest of the Silver Peak benchmark. It is a multiple dike along a dike of white granite which is broken up and intruded by the greenstone. The latter sends branches in between layers of the white granite. These branches show salbands. The rock is composed chiefly of green-brown amphibole in idiomorphic needless and lime-soda feldspar which is too altered to determine its exact nature.

Number 222 is from 2.5 kilometers north of the Silver Peak benchmark. It is from a vertical dike, one of a series nearly in a line that cuts across the basement complex in a direction about north 75 degrees west, for a distance of nearly 2 miles. It is composed chiefly of green hornblende and may be designated an hornblendite.

The diorite dikes were supposed by Professor J. E. Clayton to be older than the quartz veins, but as they cut across the veins, this is evidently an error. They are more abundant near the quartz veins in which the silver values predominate, but they do not occur along all of the silver veins and are found along some of the gold veins. They do not appear, therefore, to have exerted any influence on the kind of ore found in the veins, and inasmuch as they are later than the veins, it is improbable that they have exerted any influence whatever on the ore deposition.

PALEOZOIC SEDIMENTARY SERIES

ALGONKIAN ROCKS

Mr C. D. Walcott has established a lower limit for the Cambrian rocks, which if applied in this district will place some of the dolomites and quartzites of the Silver Peak quadrangle in the Algonkian. He writes:[16]

> "At present I draw the basal line of the Cambrian in Utah and Nevada at the bottom of the arenaceous shale, carrying the Olenellus fauna. This refers the quartzite and siliceous shales of the Wasatch and similar sections, including that of the Eureka district, and that of the Highland range of Nevada to the Algonkian Period (Era)."

On this basis the dolomite, quartzite, and the green knotted schists underlying the Olenellus zone north of the Clayton valley may be called Algonkian. This might apply as well to some of the quartzite and quartz-schist immediately west of the village of Silver Peak, and to the basal dolomite generally of Mineral ridge, as well to some similar rocks south of Cow camp. No fossils have been found in these basal dolomites and quartzites. On the geological map these basal beds are placed with the Lower Cambrian. They are referred to here more especially to call attention to the fact that the series underlies the fossiliferous Cambrian rather than to insist on the Algonkian age of the rocks, as it is quite possible that they represent the base of the Cambrian.

THE PALEOZOIC ERA

The Paleozoic fossiliferous rocks of the Silver Peak quadrangle are confined to the Cambrian and Ordovician periods. The Lower Cambrian beds are best seen in the northeast and southeast portions of the quadrangle. They are, however, well exposed on Mineral ridge west and northwest of Silver Peak. The Upper Cambrian rocks, lying unconformably on the Lower Cambrian, are best seen in the north end of the Silver Peak range, near Emigrant pass. The Ordovician rocks appear to rest conformably on the Upper Cambrian, forming one series, but have been separated from them on account of the difference in age and lithological differences. The Ordovician series is well developed in the Palmetto mountains. Except where there are intrusions of granolites, the Paleozoic rocks do not show much evidence of great disturbances before the period of uplift of the present ranges, which was probably near the close of the Tertiary era.

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[16] American Journal of Science, vol. xxxvii, 1889, pp. 374-392.

LOWER CAMBRIAN

The lowest Cambrian rocks are well seen in a remarkably fine section in the southeast portion of the quadrangle in Barrel Spring ravine, by the road from Silver Peak to Lida. From the mouth of the ravine up which the Lida road goes, at the north base of the hills to the south edge of the quadrangle, these rocks dip very evenly to the east of south at angles from 20 to 50 degrees, the average dip being in the neighborhood of 30 degrees. The lowest exposed beds are mica-slates and quartzites, with some limestone layers containing well preserved *Olenellus* of large size, more than one species of *Archeocyathus,* and other fossils, with a higher horizon of green slates and limestone beds also containing *Olenellus*[17] and in their upper portions little conical shells, probably Salterella. A still better section of the basal Cambrian beds is to be found in the hills north of Clayton valley. Here the base of the section is a dolomitic limestone and marble, perhaps 2,500 feet in thickness, overlain by massive quartzites and green knotted schists perhaps 4,000 feet in thickness. Neither the dolomite nor the quartzite contain any fossil remains, but underlie with apparent conformity the higher fossiliferous series. These beds have already been referred to as being possibly of Algonkian age. These knotted schists are seen under the microscope to be composed of minute colorless grains, probably both quartz and feldspar, with very abundant minute fibers nearly colorless, which seem to be sericite. The knots are in part chlorite and in part aggregates of opaque grains. There is a distinct schistosity, the dip being southwest at an angle of 30 degrees, and obscure traces of an original sedimentary structure dipping east 55 degrees. The bedding planes of the knotted schists are conformable with those of the banded limestone which immediately underlies a calcareous layer containing Archeocyathus. This banded limestone, in which the sedimentation planes are indicated by alternating brown and dark layers one to three inches in thickness, dips 60 degrees to the east, and the sedimentation planes are cut by a schistose structure dipping southwest 10 degrees. The line of contact between the banded limestone and the schists is parallel to the bedding planes of the limestone, and this also suggests conformity. Calcite deposited along the planes of the schistosity brings out the schistose structure plainly. The overlying Archeocyathus limestone likewise shows planes of schistosity cutting the bedding planes.

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[17] All of the Cambrian fossils from the Silver Peak quadrangle have been determined by C. D. Walcott.

Overlying the basal Archeocyathus limestone is slate containing Ethmophyllum, and above this is green Olenellus slate. In the same section, overlying the green Olenellus slates, are thick layers of thin bedded limestone with thin bedded quartzites at the east edge of the quadrangle.

In Mineral ridge, to the west and northwest of Silver Peak, the Lower Cambrian consists of Olenellus slates and dark fossiliferous limestone overlying massive dolomitic marble and quartzite.

The Lower Cambrian series as a whole, considering its great age, shows remarkably little alteration, the massive limestones and quartzites frequently giving no evidence of crushing. As a result, the fossils are at most points well preserved. At some points, however, as north of Clayton valley, a schistose structure is developed, more especially with the Olenellus slates, and is often to be observed where there has been unusual crushing of the rocks. Several of the limestone layers are crowded with little orbicular bodies. These are not certainly of organic origin, but were not found in beds known to be of Upper Cambrian or Ordovician age.

Analyses of carbonate Rocks of the Lower Cambrian

George Steiger, Analyst

	Dolomite, number 690.	Dolomite, number 468.	Dolomite, number 545.	Limestone, number 563.
Lime	28.52	30.35	34.49	52.00
Magnesia	19.19	20.19	11.38	.42
Ferrous oxide[18]	.95	1.89	....	....
Carbon-dioxide	44 09	47.21	....	....
Insoluble in boiling HCl. 1–3	7.18	.31	....	....
	99.93	99.95	....	....

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[18] Includes any Al; also any P_2O_5 or TiO_2 that may be present.

Number 690 is the basal dolomite from the section north of Clayton valley.

Number 468 is a dolomitic marble taken at the contact with the white granite of Mineral ridge, 6.3 kilometers west of north from Red mountain.

Number 545 is a dolomitic marble from near the white granite of Mineral ridge, 6.6 kilometers northeast of Red mountain.

Number 563 is Lower Cambrian limestone from the Silver Peak range, containing an abundance of little orbicules.

The isolated areas in the extreme northeast part of the quadrangle, to the south of Lone mountain, are probably Lower Cambrian, but no fossils were found in them. The rocks of these areas are for the most part highly metamorphosed by the granite of the Lone Mountain mass, the limestone being converted into marble and the argillaceous rocks into schists.

The larger portion of the higher parts of the Silver Peak range, from a point about 2 miles south of Emigrant pass to Red mountain, is made up of Lower Cambrian slates and limestones. The slates and some associated quartzites are green in color, and the microscope shows that this color is due to abundantly disseminated chlorite.

The Lower Cambrian area to the north of the Emigrant road, at the west base of the range, consists at the base of green schists containing little conical shells. Overlying the schists are limestone layers full of little orbicules. The Lower Cambrian limestone is crushed and faulted to a remarkable degree, while the overlying thin bedded limestone of Upper Cambrian age lies quite regularly at some points on this Lower Cambrian foundation, some reddish and green slate intervening at other points. The dip of the Lower Cambrian series varies. At some points it is northeast 45 degrees and at other points southeast 10 to 40 degrees. The overlying Upper Cambrian rocks in this vicinity dip rather regularly to the southeast at angles from 5 to 10 degrees.

The Lower Cambrian rocks of Mineral ridge have largely been eroded, but two higher ridges with a north-south trend remain as a capping to the pre-Cambrian complex. The small areas of Lower Cambrian rocks, represented as capping the pre-Cambrian at various points on Mineral ridge, and especially along the east base, are composed mostly of buff dolomitic marble, which is possibly of Algonkian age, as are also some quartzite masses just west of the village of Silver Peak.

The areas of supposed Cambrian rocks at the west base of the Silver Peak range, south of the Silver Peak-Fish Lake road, are mostly schistose rocks in which no fossils were found. Their age is therefore a matter of doubt. At one or two points in these areas are small masses of old igneous rocks, one of which is, perhaps, a metamorphic basalt. The areas to the north of Piper peak are also largely schist, somewhat resembling the knotted schist described in the section north of Clayton valley. In these rocks also no fossils were found. To the southeast of Cow Camp springs are several areas composed of mica-schist, red and green slate, with some quartzite and red marble. These areas afforded no fossils.

The section along Barrel Spring ravine has already been referred to. It abounds in fossils and is intruded at numerous points by dikes of acid metamorphic lavas. A rough measurement of this series of beds along Barrel Spring ravine placed the thickness at over 10,000 feet. Alcatraz island and Goat island, in the Silver Peak marsh, are made up of Olenellus slates and limestone.

UPPER CAMBRIAN

The Upper Cambrian is present in several portions of the quadrangle. It consists at the base at some points of a red limestone breccia resting with a distinct unconformity on the Lower Cambrian, as in the group of hills lying 4 miles immediately east of Silver Peak village and at the west side of the north part of the Silver Peak range 4 miles northeast of the mill of the Pacific Borax Company, in Fish Lake valley. Overlying the breccia are successively layers of thin bedded siliceous argillite, thin gray slate showing faint impressions of graptolite remains, brown slates, heavy beds of thin bedded dark limestone, red and brown slate containing well preserved minute disk-shaped shells (linguloids), some trilobites (Acrotreta), abundant fragments of Phyllocarida, and some corals.

This series is best developed in the vicinity of Emigrant pass, especially to the south of the Emigrant road, on the west side of the range. The shells are well preserved and are regarded by C. D. Walcott as indicating an Upper Cambrian age. The beds appear to conformably underlie the siliceous argillite and slate of the Ordovician, which is chiefly characterized by graptolite remains. Moreover, the Phyllocarida, so common in the Upper Cambrian, are found in layers interbedded with the graptolite slates at the base of the Ordovician, and the linguloids of the Upper Cambrian were found in slates but a few feet under the gray graptolite slate, with no evident unconformity between.

While the Upper Cambrian rocks were found in nearly all parts of the quadrangle, they are nowhere so rich in fossils as to the south of the Emigrant road. In nearly all areas the thin bedded limestone forms a conspicuous feature. In the area 5 miles east of B. M. 4996 no fossils whatever were found, and this mass is assigned to the Upper Cambrian largely because of its conformable position below the Ordovician siliceous argillite.

The Upper Cambrian beds in the Silver Peak range dip usually to the northeast. In the area 5 miles east of B. M. 4996 they dip easterly, and in the area just east of the Clayton marsh they dip northwest.

THE ORDOVICIAN SEDIMENTS

Overlying the Upper Cambrian rocks are thin, black, gray and red slates interbedded with layers of black siliceous argillite and sandstone. The slates contain at a great number of points very abundant graptolites. As noted under the Upper Cambrian, there appears to have been a continuous deposition of sediment from Upper Cambrian time to the Trenton horizon of the Ordovician.

The collections of graptolites were examined by Mr Charles Schuchert, who states that there are two horizons represented—one the Normanskill or lower Trentonian, and the other the Quebec horizon. Nearly all of the graptolites, however, belong to the Normanskill zone. In the Quebec horizon Mr Schuchert found two characteristic genera, *Didymograptus* and *Tetragraptus.*

In the Palmetto mountains and at some other points there are very numerous streaks of light colored felsitic rocks interbedded with the dark siliceous argillite of the Normanskill zone. The microscope shows that the felsitic layers are chiefly old rhyolitic or dacitic lavas and tuffs. It is thus certain that in Ordovician time there were volcanic eruptions in the region. Certain other light colored felsitic-looking layers are in part metamorphosed into garnet, pyroxene, and calcite and epidote.

Nearly all the north end of the Silver Peak range is composed, where not covered with rhyolite, of the cherts and slates of the Ordovician, containing at several points recognizable graptolites. At many places these beds are highly contorted and faulted and dip in various directions at high angles, the general strike, however, being nearly east and west. At some localities they are intersected by veins of calcite, but no quartz veins were noted in them. In the neighborhood of the Emigrant pass, both to the north and south of the Emigrant road, graptolites may be found in the rocks at many points. In nearly all of this district the beds dip in an easterly direction.

TERTIARY SEDIMENTARY SERIES

ESMERALDA FORMATION

General character.—In the central and northern part of the quadrangle there are beds of light colored marls, slates, and sandstone which were laid down in the waters of a lake. They are designated the "Esmeralda formation," after the county in which they occur. There are local developments of sedimentary breccias probably of subaerial origin and conglomerates on a large scale. The lake beds contain the remains of fresh-water mollusks and fish, which indicate that the water of the lake must have been fresh or only slightly saline. In addition, there are very abundant plant remains and beds of coal. Inasmuch as Professor Knowlton has described the fossil plants in detail elsewhere,[19] they will be only briefly referred to here. The flora is represented by ferns, the fig, oak, willow, sumach, and soapberry, and includes tree trunks 6 to 8 feet in diameter, showing that the climate has undergone a great change since Tertiary time. From a well watered region it has become an arid one in which there are no running streams.

The first published notice of these Tertiary lake beds appears to be that of M. A. Knapp, describing particularly the coal deposits[20] occurring in the beds at the north end of the Silver Peak range. Mr Knapp collected some molluscan remains near the coal beds, and these were examined by Dr J. C. Merriam, of the University of California, who considered the shells indicative of fresh water and possibly Miocene in age.

Areal distribution of the beds.—On the geological map in Spurr's report the areas of the Esmeralda formation are shown as "Tertiary stratified rocks." In the southern part of the quadrangle the beds are visible at only a few points and are undoubtedly mostly wanting, for there are older rocks at the surface nearly everywhere in the Palmetto mountains and the southern part of the Silver Peak range. The lake beds undoubtedly underlie the later deposits of Clayton valley, of the southern part of Big Smoky valley, and of the northern part of Fish Lake valley. They are also reported to have been struck in a well bored at Columbus, at the west side of the valley of that name, which lies just north of Silver Peak range. It is probable that they underlie the Columbus marsh. They certainly extend north of the Silver Peak quadrangle into Big Smoky valley. As far as present evidence goes, within the limits of the Silver Peak region the basin containing lake Esmeralda was bounded on the south by the Palmetto mountains at the south end of Clayton valley, on the east by the Montezuma mountains, and on the west by the Inyo range, the northern limit being entirely unknown. Moreover, this basin may easily have connected through the depression north of Lone mountains with the Ralston Desert basin, which lies east of the Montezuma mountains. The beds arch up over the central part of Silver Peak range, reaching an altitude of 7,000 feet at Red mountain. It is therefore clear that this portion of the range did not exist in Tertiary time, and that its site was a portion of the lake basin extending from the Inyo range on the west to the Montezuma mountains on the east. It is also clear that this portion of the range was uplifted in post-Esmeralda time. The highest part of the Silver Peak range attains an altitude of 9,500 feet, but the highest summits are made up of Tertiary lavas of later age than the lake beds.

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[19] H. W. Turner: "The Esmeralda formation, a fresh-water lake deposit," with description of the fossil plants by F. H. Knowlton and a fossil fish by F. A. Lucas. Twenty-first Annual Report of the U. S. Geological Survey, part 2, pp. 192-224.

[20] The coal fields of Esmeralda county, Nevada. Mining and Scientific Press, San Francisco, vol. lxxiv, 1897, p. 133.

It might be noted, however, that fossil fishes from this formation were collected previously by J. E. Clayton and W. P. Blake, but no description of these fossils appears to be in print. Proceedings of California Academy of Science, vol. iii, 1866, p. 306.

Basal conglomerate of the Esmeralda formation.—In the upper portion of Ice House canyon and in the ridges to the west are narrow lenses of conglomerate, often of a bright red color, containing very abundant subangular but evidently waterworn fragments of green schist, blue limestone, marble, vein-quartz, and fragments of black siliceous argillite. The green schist or slate is apparently precisely like that found in the Lower Cambrian, and the siliceous argillite is indistinguishable from the siliceous argillite of the Ordovician. These fragments are imbedded in a limestone matrix, and in this matrix there are frequently oval bodies, with a maximum diameter of 1¼ inches, which show in section a distinct concentrically laminated structure. These bodies, like the orbicules previously mentioned of the Lower Cambrian limestone, have been examined by several paleontologists, who regard them as of concretionary origin. The conglomerate lies with a marked unconformity on the Paleozoic rocks. Immediately overlying the conglomerate lenses, which are perhaps 100 feet in maximum thickness, are basalts and other lavas. Similar beds are found at the base of the Esmeralda formation, in the central part of the Silver Peak range, 3 miles northwest of the summit of Rhyolite ridge, at the head of a large ravine. Overlying the conglomerate are hardened buff sandstones.

Tertiary detrital-slope breccias.—The low, dark hills and ridges east and southeast of the south end of the Big Smoky valley are covered with loose fragments of Cambrian and Ordovician limestone, quartzite, and slate. A careful examination of these hills shows that they are made up of coarse bedded breccias, intercalated with thin sandstone layers. The beds dip at considerable angles, and farther southeast, apparently conformably overlying the breccias, are fine sediments containing fish remains. The breccias evidently represent old detrital beds of subaerial origin, and would seem to indicate oscillations of level of the waters of lake Esmeralda or local uplifts and depressions.

Conglomerate beds.—The extensive conglomerate beds 4 miles northeast of the Monocline show the action of moving water, and hence are possibly of fluviatile origin.

The Tertiary period in this region being a time of extensive volcanic activity, the outlines of the lake must have undergone frequent changes, and undoubtedly there were local upheavals and subsidences during the lake period. The coarseness of the volcanic sediments are, however, no evidence as to a shallow-water origin, since the ashes would be thrown out from volcanoes all over the lake and form coarse deposits even in deep water, where under normal conditions only fine sediments would be deposited.

Thickness of the beds.—No continuous section of the entire formation was found, but an attempt was made to estimate the approximate thickness of the beds. They dip nearly everywhere at angles varying from 5 to 60 degrees from the horizontal and are broken by numerous small faults, so that often a layer followed along the strike is found to offset from 10 to 100 feet or more every few hundred feet.

However, the lake sediments are finely exposed in the large area east of the north end of the Silver Peak range and in a northwest-southeast section constructed here across the strike of the beds. No evidence was noted of a repetition by faulting or folding, and if there is no repetition the series must have a total thickness of over 10,000 feet. Detailed evidence as to this section and other information concerning the Esmeralda formation will be found in the paper before referred to in the Twenty-first Annual Report of the U. S. Geological Survey.

NEOCENE RIVER GRAVELS

Outside of the gravels of the Esmeralda formation, there are in the southern part of the quadrangle masses of well rounded gravel which have no established connection with the lake beds. They presumably are river deposits from streams that existed at the same time as lake Esmeralda.

One of the masses lies 4½ miles south of Cow Camp spring, east of the road to Oasis; it is capped by basalt. The pebbles are well water-worn and are of granite, slate, and lava. Another lies 4½ miles southwest of Piper peak. The pebbles of this area are many of them several inches in diameter. The deposit rests on supposed Ordovician rocks, next to an area of rhyolite. Scattered pebbles are also found on the crest of the Palmetto mountains about little patches of basalt, suggesting that they are remnants of a river deposit once covered by basalt. A large area of gravel and sand lies about 5 miles north of west from Piper peak and is composed of comparatively small pebbles of a granitic rock (quartz-monzonite) and of a siliceous argillite like that of the Ordovician. It is capped by basalt and at one point lies on a bed of pumice with a second pumice layer, about 3 feet thick, intercalated in the gravels near the top of the series. The entire thickness of the formation is here over 200 feet and the beds are disturbed, dipping at some points 10 degrees or more easterly; at some places they are faulted. Exactly similar gravel is found underlying the pumice at the west end of the Piper Peak ridge.

QUATERNARY DEPOSITS.

DESERT DETRITUS

There is nothing so striking in the Great Basin region as the numerous detrital slopes, which spread out from all the canyons and fill considerable portions of the valleys. In view of the very small precipitation in this region, the formation of these numerous fans would seem to involve a very long period of time. They are composed chiefly of coarse material, often containing boulders tons in weight. When the older detrital material is cut by the present watercourses or "washes," the stratified arrangement of these materials is clearly evident. There can be no doubt that their distribution is due to the action of water. A consideration of the manner in which rain falls in all this desert country suffices to explain the formation of these detrital slopes, for although the precipitation is very small when the region as a whole is considered, it is often very great within the space of a few hours over a limited number of square miles. The action of the sun and the frost on the rocks of this dry region results in the surface rocks being everywhere extensively cracked, and the fragments, although about in their original position, are easily displaced. When a cloudburst occurs the rain runs off in torrents and sweeps before it large quantities of this loose material, and when the cloudbursts are of sufficient size they will carry boulders many tons in weight far out on the plains. There is therefore no difficulty in accounting for the formation of the alluvial fans, but the time that must be allotted to their formation, if we suppose the precipitation to have been no more in the early Pleistocene than at present, would be enormous. It is quite certain, however, that in earlier Pleistocene time the precipitation was much greater than at present. It is probable, therefore, that the larger part of these detrital slopes was formed during the first half of the Pleistocene. This would harmonize with the record in the Sierra Nevada. The larger part of Pleistocene time was required for the excavation of the canyons. This early Pleistocene period of erosion has been termed the Sierran[21] period, and the larger detrital slopes of the Great Basin is referable to this period.

The older detrital materials have undergone uplift at many points. The hills just north of the Cave Spring road and just east of Fish Lake valley are largely Pleistocene conglomerates overlying the Esmeralda formation. This conglomerate is somewhat consolidated and dips northerly at angles of 10 to 35 degrees. There may be observed in it a white layer composed of carbonate of lime. This is seen in the east face of the first hill north of the Cave Spring road, and also on the north face of the hill 4 miles northeast of the Crossing. To the south of the Cave Spring road there are heavy beds of gravels and detritus, possibly formed at the same time as the Pleistocene conglomerate, north of the road. The beds to the south of the road are not tilted, but have undergone elevation, forming a striking terrace (plate 8) facing Fish Lake valley. The recent "washes" in this terrace show a thickness at one point of 250 feet of detritus and gravel containing some boulders six feet in diameter.

There are many gravel patches mixed with angular detritus on the north slope of the Palmetto mountains and of the Silver Peak range east of the road from Silver Peak to Oasis. The altitude of these masses is approximately 6,500 feet, but they have a vertical range of several hundred feet, probably due to these loose materials creeping down the slopes. There is not much doubt, however, of their Pleistocene age, as they in part distinctly overlie Tertiary lavas. The pebbles in these masses are composed of granite, slate, and lava. Mr J. E. Spurr has noted in other ranges of mountains in western Nevada bodies of gravel, often at an elevation of 6,000 feet, which may be of the same character as those here referred to. The gravels seen by Mr Spurr are thought by him to be shore gravels formed by lakes contemporaneous with the Pliocene Shoshone lake of the Fortieth Parallel region described by Clarence King. The evidence as to the origin of these gravels in the Silver Peak region is too meager to warrant any conclusion further than they are probably Pleistocene.

In general it may be said that the rocks of the Pleistocene detrital masses are usually the same in kind as the rocks of the present drainage above them, indicating a local origin. When the older detritus is fine grained, and where it is largely volcanic, it is sometimes difficult to distinguish it from the ordinary sediments or volcanic sandstones of the Esmeralda formation. Resting on the lavas north and northeast of Piper peak, at an elevation of about 8,000 feet, there are some remarkable

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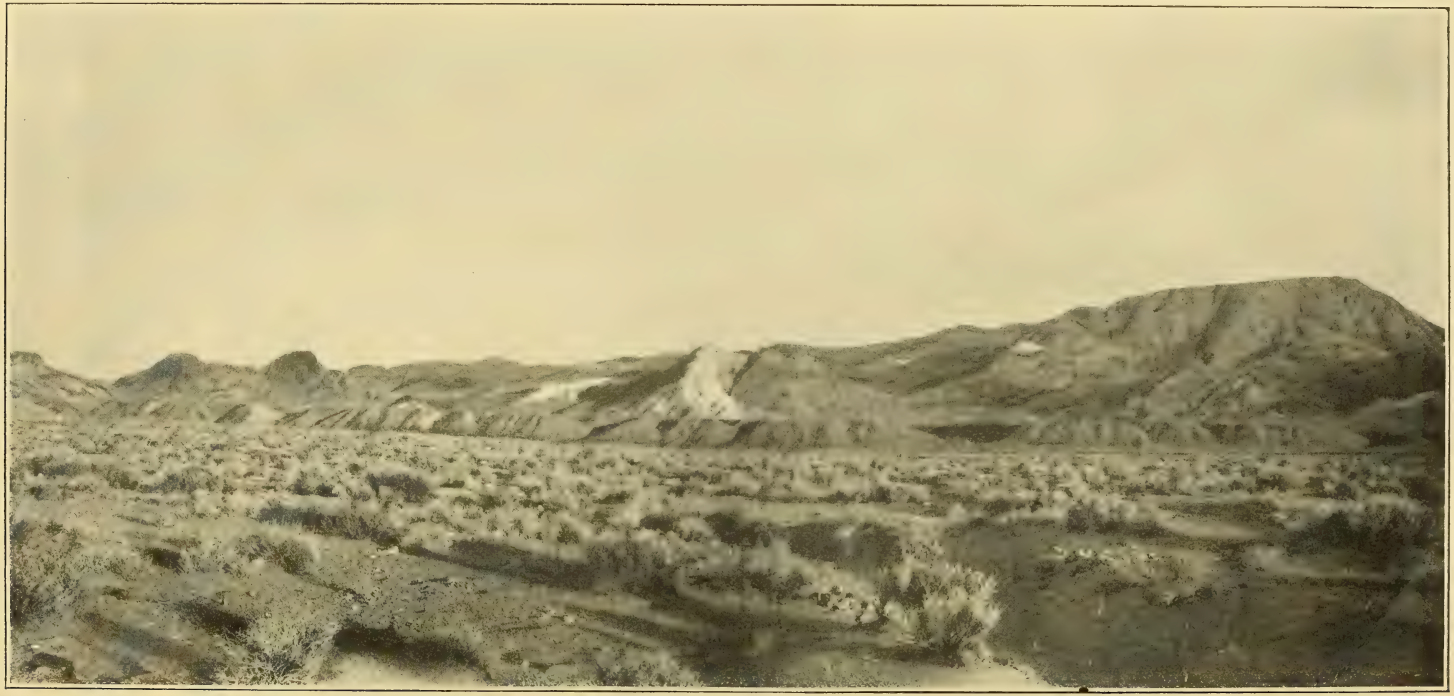
[21] Proceedings of California Academy of Science, third series, Geology, vol. 1, p. 269. The term was introduced by O. H. Hershey.



TERRACE OF EARLY PLEISTOCENE DETRITUS EAST OF FISH LAKE VALLEY

terraces composed of coarse subangular lava detritus. These appear to be referable to the early Pleistocene.

TRAVERTINE OR CALCAREOUS SPRING DEPOSITS

There are noted on the geological map, at the south end of the Clayton Valley playa and at other points, small masses of travertine, presumably formed largely in recent time. Some of them are, however, so interbedded with sandstones of the Esmeralda formation—for example, the mass one mile west of Cave spring—as to suggest a contemporaneous origin with the inclosing sandstone, and such masses may be of Tertiary age.

PLAYA DEPOSITS

The playa deposits comprise two areas in Fish Lake valley, one in Clayton valley, and one in Big Smoky valley, locally known as the San Antonio marsh. All of the playas in Fish Lake valley within the quadrangle contain borax salts and have been worked for borax. Over many square miles the Big Smoky playa shows a thin white coating which consists largely of chloride of sodium. Over other portions of the valleys are deposits of other salts, such as sulphate of soda, which are ordinarily termed alkali.

SAND DUNES

At the south end of Clayton valley is a considerable group of hills composed entirely of wind-blown sand. This is said to contain a small amount of gold distributed through it. These dunes appear to have been formed by an eddy in the air currents, which seems permanently to exist at this point. They shift about from year to year to a certain extent, but on the whole remain essentially at their present location. There are also low hillocks of sand near the San Antonio marsh in Big Smoky valley and in Fish Lake valley.

RECENT DETRITAL FANS

The latest of the alluvial fans, formed largely by the rearrangement of the materials of older fans, undoubtedly belong to Recent time.

GRANULAR IGNEOUS ROCKS

GRANITE AND SYENITE

Under this heading are described granitic rocks which are much later in age than the granites and gneisses of the pre-Cambrian complex.

The granite and syenite series comprises granolites nearly all of which are rich in alkali-feldspar.

The granite rocks of the northeast portion of the quadrangle, north of Clayton valley, are chiefly true granites and granite-porphyry, but there are here also some granite-gneisses. These rocks are composed of alkali-feldspar and quartz, with some biotite and muscovite. The alkali-feldspar varies in its character at different points—orthoclase, microcline, micropegmatite, microperthite, and albite having been detected in the specimens collected.

The south base of Lone mountain, the summit of which is not on the quadrangle, is made up of a coarse, light gray biotite-granite-gneiss containing orthoclase, microcline, micropegmatite, oligoclase, quartz, biotite, iron-oxide, titanite, and apatite. The isolated butte in the detritus lying about three-fifths of a mile south of the south base of Lone mountain is composed of an even grained granite of fine texture containing quartz, microcline, micropegmatite, and orthoclase with a little oligoclase, muscovite, and chlorite. The large area north of Weepah, 6 miles in diameter, is in part a granite-porphyry composed of phenocrysts of orthoclase, oligoclase, quartz, and biotite in a microgranular quartz-feldspar groundmass which contains a little iron oxide, apatite, and zircon, but some of the specimens collected from this area are evenly granular rocks with gneissic structure locally developed, composed of orthoclase, microcline, albite, and quartz with a little muscovite, biotite, iron oxide, and apatite. The quartz occurs in aggregates of interlocking grains of smaller size than the feldspar grains. In the southwest portion of this area there are also true granite-gneisses.

The small area that lies 3½ miles northeast of the Clayton Valley crater is composed chiefly of a coarse biotite-granite, but the northwest portion of the mass is a white medium grained quartzite-like rock which the microscope shows to be chiefly quartz and albite or soda-feldspar.

QUARTZ-MONZONITE

Granitic rocks in which the alkali and soda-lime feldspars are both present in abundance are here termed quartz-monzonite. Rocks of this type are very common in the southern portion of the quadrangle. The two large areas, shown on the map in Spurr's report, in the southern part of the Silver Peak range and as extending thence southeast to the Palmetto mountains, differ from the granolites of the other portions of the quadrangle in containing more plagioclase and biotite, and are therefore better designated by the term quartz-monzonite. They may be differentiated into two types—a coarse variety, often with porphyritic feldspars, and a medium, even-grained variety. The coarse rock forms the larger part of these two areas and is probably the older rock. This type is of rather even texture with only small porphyritic crystals in the largest area, which forms the crest of the western part of the Palmetto mountains and of the southern part of the Silver Peak range, but in the smaller area, east of Fish Lake valley, on the western flanks of the Silver Peak range, there are developed porphyritic orthoclase crystals often an inch or more in length. The area 5 miles northwest of Piper peak is also of this character.

The second type of quartz-monzonite is a medium, even-grained rock forming at some points considerable masses, the largest one noted being on the north side of the Palmetto mountains. It is probably later in age than the coarse type. The two types of quartz-monzonite just noted as occurring in the Silver Peak range form the foothills of the Inyo range, in the extreme southwest corner of the quadrangle, the coarse type here having large porphyritic crystals of orthoclase. The medium grained quartz-monzonite is present here in smaller amount and is distinctly later in age, as it contains blocks of the coarse porphyritic variety.

In the table of analyses the chemical composition of some of these rocks is indicated. It will be noted that numbers 348, 349, and 653 are true granites, but these appear to be merely facies of the quartz-monzonite magna.

Partial Analyses of Quartz-monzonite and Granite from the southern Part of Silver Peak Range

George Steiger, Analyst

	Quartz-monzonite, number 324.	Granite, number 664.	Granite, number 653.	Granite, number 348.	Soda-granite, number 349.
Silica	69.23	71.14	68.50	73.22	76.04
Lime	3.38	2.56	.60	1.52	.46
Soda	3.75	3.65	4.05	2.79	7.58
Potash	4.75	3.37	4.83	5.35	.07

Description of the Rocks Analyzed

Quartz-monzonite, specimen number 324.—Locality: In the Palmetto mountains, 10.2 kilometers southwest of Barrel spring.

Macroscopically, a light gray coarse grained granitic rock, apparently chiefly feldspar. Microscopically, a coarse grained monzonite in which the orthoclase exceeds the plagioclase in amount. Feldspar, quartz, pyroxene, and accessories.

Granite, specimen number 664.—Locality: On the east side of Fish Lake valley, 20.7 kilometers southwest of Piper peak.

Macroscopically, a fine grained light gray granite. Microscopically, an evenly granular rock composed of microcline and micropegmatite, plagioclase, quartz, biotite, epidote, and titanite.

Granite-porphyry, specimen number 653.—Locality: Silver Peak range, 10.3 kilometers south of Piper peak.

Macroscopically, a dark gray fine grained porphyry. Microscopically, a porphyry with a micro-granular spherulitic groundmass of quartz and feldspar in which are imbedded crystals of plagioclase, orthoclase, quartz, biotite and iron ore.

Granite, specimen number 348.—Locality: North slope of the Palmetto mountains, 8 kilometers south of west from Barrel spring.

Macroscopically, a fine, even grained granolite composed of feldspar and quartz with some biotite. Microscopically, the feldspar, quartz, biotite, iron oxide, and apatite. The feldspar is both plagioclase (oligoclase) and orthoclase, the former showing an idiomorphic tendency.

Soda-granite, specimen number 349.—Locality: Same area as number 348, in the Palmetto mountains 8 kilometers south of west from Barrel spring.

Macroscopically, a nearly white fine grained granite. Microscopically, a soda-granite made up of feldspar quartz, biotite, and titanite. The feldspar is chiefly albite and oligoclase.

QUARTZ-DIORITE

The dioritic areas in or near the granite area north of Weepah contain at some points quartz and may be designated as quartz-diorite. Some of the rocks of these areas contain biotite, titanite, magnetite, and apatite. In one specimen the feldspar is labradorite in lath forms with later interstitial amphibole, forming an amphibole-diabase, but this appears to be merely a facies of the diorite.

GRANULAR DIKE ROCKS

These have already been briefly described under the head of "pre-Cambrian complex" as certain greenstone dikes that cut all the other members of the complex. Sometimes these dike rocks are softer than the surrounding granite, gneiss, and schist, and their courses are then indicated by troughs, as the large dike 1.5 miles north of Silver Peak. This is probably the trap dike referred to by Lieutenant Lyle in his travels through this region in 1871.[22] These dikes are composed chiefly of plagioclase and green-brown hornblende and may in general be designated basic diorite. In true diorites, however, the feldspar is oligoclase and andesine, while in some of these dikes it is in part labradorite. By loss of feldspar and increase of hornblende, some of the greenstone dikes of the pre-Cambrian complex pass into hornblendite. An example of this is the large east-west dike before referred to, 1.5 miles north of Silver Peak.

The dioritic dikes in the Silver Peak formation to the south of the diorite areas above referred to, in the northeast portion of the quadrangle, contain as their most abundant constituent plagioclase. The amphibole is usually in the form of needles, and there is sometimes pyroxene present, as well as biotite and ilmenite.

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[22] Exploration in Nevada and Arizona. War Department, Washington, 1871, p. 49.

Diorite dikes are very abundant in the southern flanks of the Silver Peak range, both in the Ordovician sediments and in the large areas of quartz-monzonite. Many of these dikes are indicated on the geological map in Spurr's report. They appear to be normal diorites. The amphibole is often in the form of needles, and the feldspar in the form of laths. There is biotite present and secondary epidote. There are some diorite dikes in the Palmetto mountains, and very abundant diorite dikes in the slates and limestones 5 miles west of south from Piper peak.

Volcanic Rocks

AGE

The lavas of the Silver Peak quadrangle may be divided into an older series, associated with Paleozoic rocks and probably Paleozoic in age, and a later series, of Tertiary age. The Paleozoic lavas are usually much altered, which condition is expressed by the prefix *meta.* Thus there are fresh rhyolites in the Tertiary and meta-rhyolites in the Paleozoic.

META-RHYOLITE

Rhyolitic lavas which have undergone alteration are designated meta-rhyolite. In such lavas the original glassy groundmass has become more or less crystalline. Such a groundmass originally glassy is sometimes called a devitrified groundmass. The devitrified dacites or meta-dacites are here placed with the meta-rhyolites. All of the rocks grouped under the head of meta-rhyolite are presumed to be pre-Tertiary in age, and most of them are known to be of Ordovician or Cambrian age. The meta-rhyolites, so far as known, are the oldest lavas of the Silver Peak quadrangle. They form bands or lenses in Paleozoic sediments most abundantly in the Palmetto mountains, but are found in all parts of the quadrangle. No analyses were made of the lavas except from dikes. Many of these dikes are completely crystalline, and analyses of three of them indicate a high content of soda. The examination of the thin-sections of the dike rocks shows that some of them contain little or no quartz, as, for example, numbers 319 and 343 of the table of analyses. Soda-rich, completely crystalline igneous rocks may be called micro-soda-syenite or keratophyre. Number 319 evidently has the composition of an alkali-rich andesite or latite and number 343 of a quartz-keratophyre or soda-rhyolite. Other dikes are fine grained and evenly granular, and to such completely crystalline rhyolitic lavas the term micro-granite is sometimes applied.

Some of the meta-rhyolites contain microperthite. There is thus a considerable variety of rocks, especially dike rocks, included on the geological map under the term meta-rhyolite.

Partial Analyses of Soda Meta-latite, Meta-rhyolite and Keratophyre

George Steiger, Analyst

	Number 319.	Number 343.	Number 313.
Silica	56.34	68.40	80.60
Lime	4.01	2.83	.18
Soda	6.32	9.00	6.04
Potash	2.63	none	none

Felsitic rock, specimen number 319.—Locality: In the Palmetto mountains, 11.7 kilometers southwest of Barrel spring.

Macroscopically, a fine grained flinty rock, slightly brownish in color. Microscopically, a felsitic rock of undetermined composition, filled with secondary products. The chemical composition is that of an alkali-rich andesite or latite.

Soda-syenite-porphyry or keratophyre, specimen number 343.—Locality: Dike in the Ordovician cherts of the Palmetto mountains, 5.5 kilometers southwest of Barrel spring.

Macroscopically, a light colored, slightly brownish rock showing porphyritic feldspars. Microscopically, a porphyritic rock with a micro-granular quartz-feldspar groundmass in which are prisms of albite and oligoclase. Monoclinic pyroxene is rather abundant, and there is a secondary mineral, apparently epidote, present.

Soda-meta-rhyolite or quartz-keratophyre, specimen number 313.—Locality: Dike in Lower Cambrian rocks, 2.6 kilometers southeast of Barrel spring.

Macroscopically, a nearly white, fine grained, apparently holocrystalline rock. Microscopically, a porphyritic rock with a micro-granular quartz-albite groundmass crowded with spherulites and phenocrysts of quartz and albite.

The Tertiary lavas are grouped under the general names basalt, andesite, and rhyolite. There is, however, considerable variety in the rocks included under these names, as will be indicated in the special descriptions.

RHYOLITE AND DACITE

Under this head are included all the acid lavas, rhyolites, and dacites, which when sufficiently crystalline usually contain free silica or quartz and a variable amount of sanidine. There are large areas of rhyolite in all parts of the quadrangle, mostly in the form of tuff or volcanic ashes. As a rule, the tuffs are arranged in layers, like sedimentary rocks, but where masses attain a great thickness, as near Emigrant peak, stratification is not always to be observed. More often than otherwise the rhyolites of the quadrangle are largely made up of volcanic glass partly in the porous form known as pumice. At some points the magma became almost completely crystalline, as with number 93 of the table of analyses. At other points, to the south of Red mountain, the rhyolite crystallized in little spherulites in which are imbedded crystals of sanidine, quartz, brown biotite, and other minerals. The rhyolite of the upper part of Red mountain is red in color and shows flow structure beautifully. It is mostly devitrified and might appropriately be called meta-rhyolite. For the purpose of distinction, however, that term will here be used only for pre-Tertiary rhyolite. The rhyolite shown at various points on the map near basalt areas is usually pumice, and the frequent association of the two lavas, basalt and pumice, suggests that perhaps both came from the same magma, the lower specific gravity of the rhyolite pumice causing it to separate from the heavier basalt.

Dacites or acid quartz-andesites are not present in large amount. They form in the rhyolite tuffs layers which are conspicuous by reason of their darker color, and are upon nearer inspection found to be made up largely of a dark glass rich in biotite. These layers are usually less than 50 feet in thickness and seem to occur at a rather definite horizon in the tuffs, as if erupted at about the same period. One of these layers may be seen along the road east of Cave spring and others in the rhyolite tuffs southeast of Piper peak. There are beds of pumice in the conglomerate of the Esmeralda formation east of the south end of Big Smoky valley and in the gravels assigned to the same formation north of the west end of Piper Peak ridge.

There are beds of rhyolite sandstone overlying the marls east of the Clayton Valley playa. These sandstones, although in places they are composed nearly entirely of rhyolite material, are placed in the Esmeralda formation, and this is likewise the case with similar beds in the north end of Fish Lake valley.

Analyses of rhyolitic lavas

George Steiger, Analyst

	Tuff, number 336.	Dacite, number 53.	Spherulitic rhyolite, number 506.	Rhyolite-granophyre, number 93.
SiO_2	64.78	69.76	72.54	75.93
TiO_2	....	0.19	0.35	....
Al_2O_3	....	14.05	13.32	....
Fe_2O_3	none	none	0.09	....
FeO	....	2.05	2.41	....
MgO	....	0.17	0.51	....
CaO	2.07	1.73[23]	1.37	1.37
Na_2O	3.72	3.90	3.40	2.80
K_2O	5.13	3.57	5.25	4.49
H_2O-	....	0.62	0.21	....
H_2O+	....	3.65	0.97	....
ZrO_2	....	....	0.06	....
CO_2	....	none	none	....
P_2O_5	....	0.07	0.11	....
MnO	....	0.10	none	....
BaO	....	0.14	0.03	....
	....	100.00	100.62	....

Tuff number 336 came from a rhyolite-tuff area. The rock is composed of particles of compact rhyolite, pumice, feldspar, quartz, and dark microlitic lava fragments, apparently andesite. These andesitic fragments undoubtedly account for the chemical composition as given in the partial analysis, which shows too much lime and too little silica for a typical rhyolite.

Dacite number 53 is a black glassy lava in which are imbedded phenocrysts of plagioclase, sanidine, and possibly some quartz, but no positive uniaxial figure was obtained. The plagioclase is both albite and labradorite. There are abundant phenocrysts of biotite and some of hornblende and augite. Magnetite and apatite are present.

Spherulitic rhyolite number 506 is from 3.9 kilometers southeast of Red mountain. It is composed of radial spherulites which have an index of refraction less than that of the balsam, and hence probably are made up chiefly of orthoclase. In this spherulitic groundmass are imbedded crystals of sanidine, quartz, reddish brown biotite, a little amphibole, and a little plagioclase, apparently oligoclase. There are numerous prisms of titanite, some of which is pleochroic in greenish colors. There are grains of magnetite, and zircon must be present, as it is indicated by the chemical analysis.

Rhyolite-granophyre number 93 is from 3.6 kilometers northeast of Emigrant peak. It shows a microgranular groundmass largely feldspathic, in which are imbedded abundant phenocrysts of quartz which are sometimes idiomorphic, sometimes much corroded, angular sanidines not corroded, and a little biotite.

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[23] Includes any SrO.

The rhyolitic areas about the north end of Fish Lake valley contain much pumice and perlite, and rounded fragments of black obsidian. These fragments appear to owe their rounded form to having been blown into the air from the volcano while cooling. There are dark brown layers of dacite in these rhyolitic areas and more or less rhyolitic sandstone.

Rhyolite ridge is a very picturesque accumulation of rhyolitic sandstones and tuffs with one or more layers of darker dacite. The sandstones and tuffs are very regularly bedded, dipping to the west usually at low angles. The rocks are mostly of a light buff color, with some red layers, the stratification being magnificently shown on the nearly perpendicular bluffs of the east side.

ANDESITE

Andesite forms large areas in the quadrangle, chiefly in the form of breccias or tuffs. Such is the andesite of the north foothills of the Palmetto mountains, those about Cow camp, and elsewhere. There are, however, massive lavas of coarse grain, which are here placed with the andesites because of the difficulty of separating these rocks from true andesites in the field. These massive lavas differ mineralogically from andesites proper in containing orthoclase in the groundmass. Their chemical composition is indicated by analysis number 27. It will be seen that this rock is low in lime and rich in potash when compared with a typical andesite. The large andesite area northeast of Piper Peak basalt area contains much of this alkali-rich type, which approximates in composition to the latites of Dr F. L. Ransome.[24]

Partial Analysis of Latite-granophyre, Number 27

George Steiger, Analyst

Silica	64.28
Lime	3.79
Soda	3.97
Potash	4.55

Specimen number 27 is a coarse grained gray lava from the west slope of the Silver Peak range, south of the Cave Spring road. It shows large plagioclases up to one-half inch or more in diameter. Microscopically, the rock has a microgranular groundmass which gives a Becke reaction for alkaline feldspar. In this groundmass are imbedded phenocrysts of andesine, labradorite, biotite, and augite. Magnetite and apatite are present as accessories.

BASALT

Dark feldspathic lavas containing basic plagioclase or labradorite and the ferro-magnesian silicates, pyroxene, and olivine are called basalt.

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[24] Sonora folio and Bulletin no. 89, U. S. Geological Survey.

Such rocks are abundant in the quadrangle. The largest flow is that of Piper Peak ridge. This basalt differs from the other flows in being rather coarse in grain and in containing more hypersthene than olivine. Chemically this rock is richer in silica than most basalts, as may be seen in the following analysis:

Partial Analysis of the Basalt of Piper Peak, Number 590

George Steiger, Analyst

Silica	54.78
Magnesia	3.55
Lime	7.48
Soda	3.28
Potash	2.44

Most of the basalts of the quadrangle are of the ordinary olivinitic type. They are dark heavy rocks, often scoriaceous, usually showing minute yellow grains (olivine) to the unaided eye.

The Pleistocene basalt of the Clayton Valley crater is largely in the form of lapilli; that is, more or less rounded, scoriaceous fragments.

The Succession of the Lavas

IN GENERAL

The oldest lavas observed in the region are the meta-rhyolites and associated lavas of the Cambrian and Ordovician periods.

Between Paleozoic and Tertiary time there appears to have been a cessation of volcanic activity.

In the Tertiary era the quadrangle was the scene of frequent and prolonged eruptions, and the lavas and tuffs of this era are so related to the deposits of the Esmeralda formation that the age of some of the eruptions has been in part definitely ascertained.

OLDER BASALT

What are perhaps the oldest lavas are certain basalts which form narrow bands near the supposed base of the Esmeralda formation in Ice House canyon and vicinity, associated with red conglomerate beds.

OLDER ANDESITE

South of the Cave Spring road, at the west base of the Silver Peak range, are dikes and intruded sheets of altered andesites in the there hardened sandstones. These may be as old as the basalts above referred to.

OLDER DACITE

In the Miocene sandstones and slates near the coal mines are interbedded layers of a dacite-tuff. This is composed of crystals, broken or entire, of plagioclase, sanidine, quartz, and biotite, in a groundmass that appears to be devitrified glass. A similar dacite, but massive instead of fragmental, is found farther west, at the north base of the range, and this is probably of the same age as the tuff in the Miocene beds.

ANDESITE AND RHYOLITE

Higher up in the lake beds, apparently near the middle of the formation, are rhyolite and andesite tuffs, the andesite being of the normal type. In the ravines at the east base of the Silver Peak range, just south of the Emigrant road, there is a layer of andesitic breccia about 20 feet thick, interstratified with lacustral marls, and 200 feet higher up, or to the east, is a thicker layer of rhyolitic tuff. Both of these layers contain silicified wood. What are perhaps the same layers are to be seen in the lake beds to the east of the Silver Peak road, in the south end of Big Smoky valley. There are also pebbles of andesite and rhyolite in the older conglomerates of the Esmeralda formation, about 3 miles west of Rhyolite ridge. A very striking evidence of the succession of lavas is seen in the ridge west of Ice House canyon when viewed from Fish Lake valley. At the west base are gray andesite breccias 800 feet in thickness; next, white rhyolite tuffs of about the same thickness capped with a flow of dark basalt; but if we go up Ice House canyon we will observe that the succession is not so simple, for overlying the rhyolite tuffs above referred to is another extensive andesite-tuff area, succeeded by other rhyolite tuffs and pumice, which to the east of the canyon are associated with and appear to be interbedded with sandstones of the Esmeralda formation.

The highest, and therefore most recent, tuffs and pumice beds are finally capped by the coarse basalt of the Piper Peak flow, which is an hypersthene-basalt, while that of the ridge west of the Ice House canyon is a normal, dark, fine grained, olivine basalt.

The succession of lavas in Ice House canyon would then apparently be:

1. Older basalt associated with the red basal conglomerate of the Esmeralda formation.
2. Andesite-breccia.
3. Rhyolite-tuff.
4. Andesite-breccia.
5. Rhyolite-tuff and pumice.
6. Hypersthene-basalt of Piper peak.
7. Dark fine grained olivine-basalt, which may or may not be later than the Piper Peak flow.

In the northern foothills of the Palmetto mountains and the adjacent foothills of the Silver Peak range there are extensive areas of hornblende and pyroxene-andesite overlying rhyolitic tuffs and pumice, and this is true of nearly all occurrences in these foothills. An exception is to be noted in the basin 6.5 miles southeast of Cow camp, where there is a later white pumice (presumably rhyolitic) overlying andesite-breccia and conglomerate. This pumice should probably be correlated with the pumice beds of the Monocline, which are possibly of early Pleistocene age.

LATITE

The alkali-rich andesite or latite of the ridges north of Piper peak distinctly overlies the rhyolite-tuffs of that region.

LATER DACITE

The occurrence of a dacite near the base of the Esmeralda formation, at the north end of the Silver Peak range, has already been noted. This is undoubtedly older than the bulk of the true rhyolites. At many points there are layers of a later dacite intercalated in the rhyolitic tuffs. This is the dark glassy variety represented by analysis number 53. These layers can be seen along the south base of Rhyolite ridge and to the southwest of Piper peak as well as at many other points. We thus have eruptions of dacite of two periods—one near the beginning and one near the middle of the Tertiary volcanic period.

HYPERSTHENE-BASALT

The coarse basalt of the Piper Peak ridge overlies rhyolitic pumice at many points. It also overlies the massive alkali-rich andesite or latite of the north end of the high ridge that extends north from Piper peak.

OLIVINE-BASALT

An older basalt has already been referred to. Near the west end of Piper peak ridge there are olivine-basalts which form layers in rhyolitic tuffs and gravel beds; but these layers are pretty certainly intruded sheets and of the same age as the similar basalts which cap the same gravels of the Esmeralda formation in the vicinity. Basalt overlies andesite about 2 miles northeast of Barrel spring.

Olivine-basalt overlies rhyolitic tuffs and pumice at the Monocline and other neighboring points; also on the high butte 5 miles southwest of Silver Peak; also on the table mountain 5 miles southwest of Piper peak, and, as already noted, on the high ridge west of Ice House canyon. In general it may be said that the basalts form the latest lavas of the quadrangle.

PLEISTOCENE BASALT

Finally there may be mentioned the basalt of the Clayton Valley crater, undoubtedly of Pleistocene age and representing the last volcanic eruption of the quadrangle.

We may then summarize the succession of the lavas as follows:

Older basalt ?
Older andesite ?
Older dacite ?
Andesite ?
Rhyolite.
Andesite.
Rhyolite.
Alkali-rich andesite or latite.
Piper Peak hypersthene-basalt.
Dark olivine-basalt.
Clayton Valley crater basalt.

If we omit consideration of the older basalt, which apparently nowhere was erupted in any considerable mass, we have a repetition of eruptions of intermediate (andesite) and acid (rhyolitic and dacitic) magmas, culminating with basic lavas (basalt).

CONTACT METAMORPHISM

PYROXENITE

The Paleozoic section north of Clayton valley has already been referred to. The large area in which this section was measured contains numerous dikes. They are in part acid lavas and in part diorite. At one point on the northwest side of the area are small bodies of a green pyroxene rock, along the contact of an intrusive hornblende-mica-gabbro. This pyroxenite may have formed from the metamorphism of the adjoining dolomite, inasmuch as the dolomite itself contains monoclinic pyroxene in isolated grains and groups of grains. At another locality, at the contact of limestone with a granite mass, another lime silicate mineral, vesuvianite (see analysis below), formed, mixed with garnet and quartz. Some of the slates along the contact were metamorphosed likewise into schists. The pyroxene in the dolomite and the vesuvianite appear to be contact metamorphic products formed by recrystallization due to the heat and vapors of the intrusive granite rocks.

Analysis of Vesuvianite, Specimen Number 186[25]

George Steiger, Analyst

SiO_2	36.80
TiO_2	0.66
Al_2O_3	17.53
Fe_2O_3	1.56
FeO	3.27
MnO	0.48
MgO	1.23
CaO	35.00

Na_2O K_2O	0.13
H_2O —	.10
H_2O +	1.56
CO_2	.65
P_2O_5	.07
SO_3	none
Cl	none
F	.88
BaO	none
	99.92
Less O equal to F	.36
	99.56

Boron was looked for, but not detected by blowpipe test.

SERPENTINE

In the Palmetto mountains, at the south end of the quadrangle, there are a few small masses of serpentine. These areas lie at the contact of quartz-monzonite and other rocks, in part meta-rhyolite and in part limestone or dolomite and chert. There is more or less carbonate of lime in the serpentine and frequently bunches of pyroxenite, and the pyroxene of this rock appears to be the original mineral of the serpentine. An analysis of the pyroxene shows it to approximate to diopside in composition.

Analysis of Pyroxene from Specimen Number 323

George Steiger, Analyst

SiO_2	46.04
Al_2O_3	1.21[26]
Fe_2O_3	5.24[27]
MgO	16.98
CaO	25.23

It has been shown that diopside is sometimes formed by the metamorphism of magnesian limestone,[28] the diopside afterwards altering into serpentine. It is regarded as probable that like transformations account for the serpentine of the Palmetto mountains.

CHLOROPAL

In a streak of a light colored felsitic rock inclosed in Ordovician chert,

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[25] The vesuvianite was freed from the associated garnet and quartz by means of the Thoulet solution.—H. W. T.

[26] Includes any TiO_2 and P_2O_5 that may be present.

[27] Includes any Fe O calculated as Fe_2O_3.

[28] G. P. Merrill: On the serpentine of Montville, New Jersey. Proceedings of the U. S. National Museum, vol. 11, pp. 105-111.

there was found a sort of vein deposit of a yellowish material. The locality is about 15 miles southwest of Silver Peak. A sample of the rock was treated chemically with the following results:

Analysis of yellow Mineral, Specimen Number 391

George Steiger, Analyst

Insoluble, less SiO_2; soluble in Na_2CO_3 after treatment with HCl	51.5
SiO_2 after treatment with HCl	19.0
Fe_2O_3 soluble in HCl	13.5
CaO soluble in HCl	3.4
MgO soluble in HCl	.5
Alkalies	none
H_2O calculated by difference	9.5
CO_2 calculated from CaO	2.6
	100.0

Leaving out CaO, CO_2, and insoluble less silica soluble in Na_2CO_3, and calculating to 100 per cent:

SiO_2	44.8
Fe_2O_3	31.8
MgO	1.2
H_2O	22.2
	100.0

The yellow mineral removed from the impurities thus corresponds closely with chloropal.

STRUCTURAL FEATURES

It appears probable that the valleys of the region are in part or perhaps largely of orographic origin; that is to say, they represent subsided areas. Elevation of ranges and subsidence of valleys may be presumed to go on simultaneously. Such movements are usually accompanied by normal faulting, and there is good evidence outside of the topography that normal faulting has taken place in the quadrangle.

One of the demonstrated fault-planes lies at the north base of the Silver Peak range, and the steep north slope is ascribed to uplift along this fault. It is perhaps hardly correct to call this steep slope and other similar slopes a faultscarp, for the original scarp has long since been removed by erosion. Figure 2, plate 9, is a view of this scarp from the north. The rocks of the scarp are in large part rhyolitic tuffs and massive rhyolite. Ordovician sediments form a portion of the western part of it. To the north of the scarp are the lake beds (Esmeralda formation). These consist here largely of sandstone containing coal seams. At the contact with the scarp these beds are highly contorted and broken and at some points stand vertical. A basalt dike has been intruded along the fault, and this is shown as a dark ridge in the middle of figure 2, plate 9. I am informed that a thirty-foot gouge was passed through in prospecting a coal seam close to the fault. This doubtless represents the exact line of faulting. To the north of the fault zone the sandstones dip evenly to the north at angles of from 25 to 35 degrees. This line of faulting was first recognized by M. A. Knapp, a mining engineer, when examining the coal beds.

The steep north slope of the Palmetto mountains is also regarded as due to uplift along a normal east-west fault, the existence of which is further indicated by a rhyolite dike intruded along a part of it and by a line of vigorous springs, two of which are shown on the topographic map, one being at Indian Garden. Some of these springs are warm. What is presumably a continuation of this line of faulting is a fault wall (shown in figure 1, plate 9) in the northern foothills of the southeast end of the Silver Peak range. This wall shows slickensides. It is composed of a friction breccia of rhyolite hardened by infiltrating waters, and was traced by exposures similar to that shown in figure 1, plate 9, for a considerable distance. Other croppings of this fault breccia may be noted in the distance in the figure.

The slates and limestones of the Lower Cambrian of the west side of the Silver Peak range south of Emigrant pass have been uplifted along a north-south normal fault for a distance of several miles, and the coarse conglomerate beds of the Esmeralda formation here dip to the west or away from the fault line, and at the fault line itself there is distinct evidence of faulting.

What is probably a strong north-south fault zone forms the steep escarpment facing west of the rhyolite hills 10 miles southeast of Silver Peak. The north continuation of this fault line is east of the Silver Peak quadrangle. It is expressed in a steep scarp of Paleozoic rocks (probably Cambrian) that lies 8 miles due east of Silver Peak, exposing a very fine section that has not yet been examined by a geologist, so far as known. Still farther north the northeast end of the Clayton marsh abuts against this fault wall, the continuance of which still farther northward is indicated by a narrow north-south valley.

Smaller faults of the normal type are abundant, erosion along them often forming vertical walls which show smoothing and grooving due to movements along the faults. One of these walls has been used as a wall to a storehouse near the spring that furnishes drinking water to the town of Silver Peak.

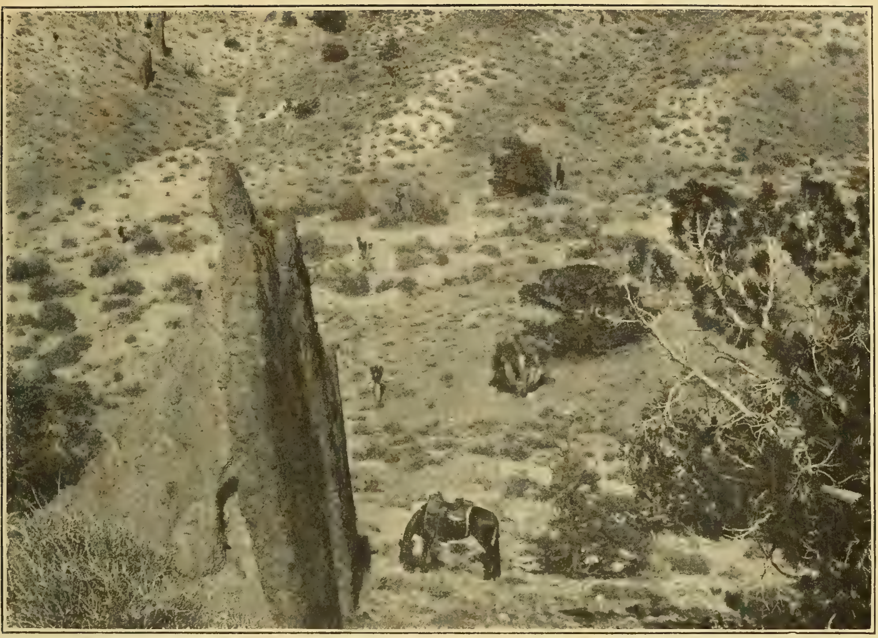

FIGURE 1.—FAULT WALL, HARDENED BY INFILTRATED WATER, AND SUBSEQUENTLY EXPOSED BY EROSION

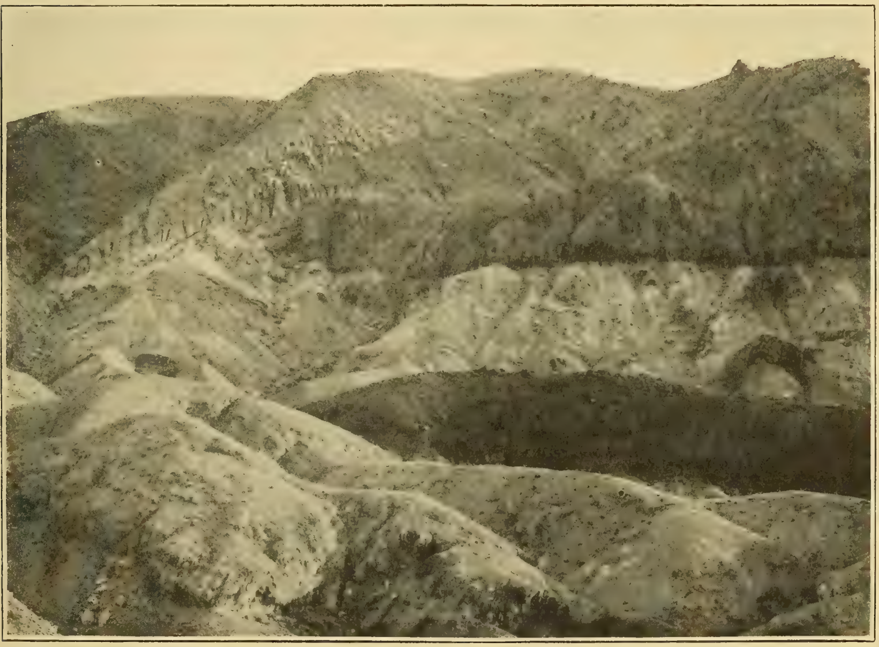

FIGURE 2.—BEDDED VOLCANIC ROCKS AT THE NORTH END OF THE SILVER PEAK RANGE

FAULT WALL AND BEDDED VOLCANIC ROCKS, SILVER PEAK RANGE

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KINDERHOOK FAUNAL STUDIES—V, THE FAUNA OF THE FERN GLEN FORMATION[1]

BY STUART WELLER

(*Presented before the Society December 31, 1908*)

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INTRODUCTION

The present contribution to our knowledge of the Kinderhook faunas differs from those which have preceded it in including material which has been collected from several distinct geographic localities. The Fern Glen formation was first described in connection with the discussion of the Glen Park section, in "Kinderhook Faunal Studies, IV."[2] It is a highly characteristic formation, consisting of beds of red calcareous shales which often graduate into red limestones. The lower limit of the formation is usually sharply defined, but toward its summit it passes gradually into greenish, shaly, calcareous beds, and these in turn merge gradually into the superjacent light colored, cherty Burlington limestone. The type locality of the formation is in the bluffs of the Meramec river, in the railroad cut just west of Fern Glen station, on the Missouri Pacific railroad, about 20 miles west of Saint Louis. At this locality the section exposed is as follows:

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[1] Kinderhook Faunal Studies I, II, III, and IV have been published in Transactions of the Saint Louis Academy of Science, vols. ix, x, xi, and xvi.

Manuscript received by the Secretary of the Society December 31, 1908.

[2] Transactions of the Saint Louis Academy of Science, vol. xvi, p. 438.

5. Gray limestone with an abundance of chert; outcrops mostly covered with soil and talus upon the slope of the hill. This is the typical Burlington limestone.................................Thickness, 25 feet
4. Greenish calcareous shales with an abundance of chert in bands which are more or less continuous. Toward the base the beds are somewhat variegated with the red color of the subjacent bed ....Thickness, 14 feet
3. Red calcareous shales, highly fossiliferous, with a persistent chert band at the summit 6 inches in thickness. In the midst of the bed occasional more or less continuous chert bands occur, but they are far less conspicuous than in the bed above..............Thickness, 12 feet
2. Hard, red, more or less crystalline limestone, with numerous crinoid stems and other fossils similar to those in the superjacent bed. Thickness, 14 feet
1. Hard, tough limestone, similar to that above, but of a buff color. Exposed thickness, 2 feet

In this section beds number 2 and number 3 typically represent the Fern Glen formation, but bed number 4 is a transition from the typical Fern Glen to the Burlington limestone, and although it is not so fossiliferous as the red beds below, its fossils seem to be identical with them. Under these circumstances bed number 4 should probably be considered as a part of the Fern Glen, making the total thickness of the formation at this point 40 feet.

Another locality of the Fern Glen formation which has furnished an abundance of fossils is near Kimmswick, Jefferson county, Missouri. This locality is in a railroad cut of the Saint Louis, Iron Mountain and Southern railroad, a little over one mile south of Kimmswick and about 2 miles north of the Glen Park section noted in Kinderhook Faunal Studies, number IV, describing the Glen Park fauna. The section at this locality is as follows:

8. Light colored gray limestone, or often with a greenish color, especially below, with a large amount of chert in bands. At the summit this bed is doubtless true Burlington limestone, but the lower portion represents the transition beds from the Fern Glen to the Burlington.....................Thickness, 20 feet

7. Red calcareous shales, highly fossiliferous, with some chert in bands toward the summit. This bed is identical, faunally and lithologically, with the typical shaly Fern Glen bed number 3 in the last section described................Thickness, 15 feet
6. Hard, tough limestone of a yellowish or buff color, sometimes a little greenish, exactly similar to bed number 1 of the Fern Glen section.................................Thickness, 4½ to 6 feet
5. Greenish sandstone with numerous waterworn black pebbles. Some of the pebbles show the structure of fish teeth of the genus *Ptyctodus*. This bed exhibits many of the characteristics of the Phelps sandstone at the base of the Kinderhook in southwestern and central Missouri, and while it may not be strictly contemporaneous with that formation, it is perhaps homotaxial with it ....Thickness, 0 to 1 foot
4. Fissile shale, brownish in color when fresh and damp, weathering to light yellow, greenish, or gray. No fossils observed except at about one foot below the top, where an abundance of Graptolites occur. This bed represents a portion of the Maquoketa shale of Upper Ordovician age, and the line between it and the bed above is a line of unconformity. Thickness, 15 feet
3. Yellowish shale with harder, gritty, apparently magnesian bands 2 to 3 inches in thickness. About one foot from the bottom is a thin layer with irregular, phosphatic nodules and numerous diminutive pelecypod shells of the typical basal Maquoketa fauna ....Thickness, 16 feet
2. Hard, more or less impure limestone, darker than that below, with the typical *Rhynchotrema capax* fauna of the Richmond beds. This bed lies unconformably on the subjacent limestone .... Thickness, ± 2 feet
1. Light colored, nearly white or flesh colored, highly crystalline limestone, some beds highly fossiliferous—the Kimmswick limestone of Trenton age............................Thickness, 40 feet

In this section the total thickness of beds which can be referred to the Fern Glen formation is probably about 30 feet, including the whole of bed number 7 and the lower portion of bed number 8. The limestone bed number 6 is apparently the same as bed number 1 in the Fern Glen section, the lower, more calcareous red member of the Fern Glen formation at its typical locality not being developed in this Kimmswick section.

In Monroe county, Illinois, nearly opposite the Kimmswick locality in Missouri, the Fern Glen beds are well exposed in the bluffs at Salt Lick point, opposite Valmeyer. At this locality a large quarry has been operated in the Kimmswick limestone in the lower portion of the bluff, the beds under consideration being exposed near the summit. The section at this locality is as follows:

4. Red limestone, with red calcareous partings—the Fern Glen formation ....Thickness, 23 feet

3. Yellow and green shales, mostly covered with talus and soil—the Maquoketa shale	Thickness,	80 feet
2. Limestone, more impure and somewhat harder and darker colored than that below, with the typical *Rhynchotrema capax* fauna of the Richmond	Thickness,	1 foot
1. Highly crystalline, pinkish or light colored Kimmswick limestone, with numerous fossils at some horizons	Thickness,	100 feet

Still farther south these beds are exposed in the Mississippi River bluffs in the northern portion of Saint Genevieve county, Missouri, but the writer has had no opportunity to study them in these localities.

North of Saint Louis these Fern Glen beds have been observed at but a single locality, in the Mississippi River bluff just east of the station at Chautauqua, in Jersey county, Illinois, on the Chicago, Peoria and Saint Louis railroad. At this point the section is as follows:

7. Typical Burlington limestone with an abundance of chert in bands	Thickness not measured	
6. Greenish, more or less argillaceous limestone with chert bands.	Thickness,	12 feet
5. Yellow, apparently magnesian limestone with chert bands.	Thickness,	4½ feet
4. Greenish limestone with numerous crinoid stems and abundant chert in bands from 1 to 4 inches in thickness. Some shaly beds are present and the bed becomes more shaly below.	Thickness,	13½ feet
3. Red, calcareous, argillaceous bed, typical of the Fern Glen formation	Thickness,	1½ feet
2. Greenish, shaly limestone with some chert bands	Thickness,	3½ feet
1. Hard, gray, or yellowish, more or less crystalline limestone, with occasional chert bands; heavier bedded below, becoming thinner bedded and more cherty above	Thickness,	10½ feet

Besides the actual exposures of the Fern Glen formation, these beds have been recognized in deep-well sections, both within the area limited by the surface outcrops and also outside of this area. The peculiar lithologic character of the beds, particularly their color, renders the formation especially easy of recognition in well sections, and it has been found to be of especial value in the correlation of such sections. The formation is distinctly recognizable in three deep-well sections within the Saint Louis area, in the Asylum well and the Belcher well in Saint Louis, and in the Monks Mound well in Saint Clair county, Illinois, all these sections being within the area limited by the surface outcrops of the formation. At a distance from this region the Fern Glen formation is clearly recognizable in a deep-well section at Chester, Illinois, where it occurs at a depth of 1,656 feet with a thickness of about 30 feet.

In northern Arkansas the red Saint Joe marble is a widespread formation, occurring at the base of the Boone Chert series with a usual thickness of from 25 to 40 feet.[3] This formation is sharply demarked below, but merges gradually into the overlying gray or white cherty limestones, which are the exact equivalent of the Burlington limestone of the Mississippi valley. The Saint Joe marble therefore occupies the exact stratigraphic position of the Fern Glen beds of the Mississippi valley; in lithologic features also, especially in its color and in the comparative freedom from chert, the two formations are closely similar. In the Mississippi valley, however, there is a much larger content of argillaceous material in the formation, but a hand specimen from the red limestone bed number 2 of the typical Fern Glen section is indistinguishable from many similar specimens of the Saint Joe marble from Arkansas. The comparison of the Fern Glen fauna with that of the Saint Joe marble will be considered later, but it may be stated here that some of the most characteristic Fern Glen species occur also in the Saint Joe. The geographic distribution of the Saint Joe marble in Arkansas is chiefly in the valley of the White river and its tributaries, from near Mountain View, Stone county, at about the northern central portion of the state, to the neighborhood of Eureka Springs, Carroll county, in the northwestern portion of the state.

Description of Species

FOSSIL LOCALITIES

The specimens used in the preparation of the following descriptions of species were collected from the four localities at which the sections are given above, the Fern Glen and Kimmswick localities having furnished the greater number. Most of the specimens used were collected by the writer, but a most valuable addition to them is the collection from Fern Glen made by Mr F. A. Sampson, of Columbia, Missouri. Mr Sampson generously placed his entire collection of Fern Glen material at the disposal of the writer for study, and some of the species, notably among the crinoids, have not been met with elsewhere.

CŒLENTERATA

ANTHOZOA

CYATHAXONIA ARCUATA n. sp.

Plate 10, figures 12, 13

Description.—Corallum cylindrico-conical, curved, becoming regularly straighter toward the larger extremity, pointed below, increasing in diameter very gradually. Epitheca thin, without spinous outgrowths of any kind, marked by low, broad, more or less indistinct longitudinal costæ which correspond in position with the septa; also by fine annular striæ and by more or less inconspicuous annular wrinkles. Calyx of moderate depth, septa 34 or 36 in number, which, as seen in polished sections, are arranged in pairs. The central axis of the corallum occupied by a strong columella, which is prominently extended upward in the bottom of the calyx. Dissepiments few, curving upward in passing from the outer wall to the columella.

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[3] Arkansas Geological Survey; Annual Report of the State Geologist for 1890, vol. 4, p. 254.

The dimensions of a large individual are: Length along the convex side, 36 millimeters; diameter at rim of calyx, 7 millimeters.

Remarks.—This species differs from *C. cynodon* R. & C., as described by Milne-Edwards and Haime, from the lower Mississippian strata in the hills south of Louisville, Kentucky, in the absence of the longitudinal series of fine spines upon the epitheca, in the greater curvature of the corallum, and in the shorter and blunter extension of the columella in the calyx.

As compared with *C. tantilla* (S. A. M.),[4] from the Chouteau limestone of central Missouri, the species is much larger, more curved, with a larger number of septa, and with comparatively fainter longitudinal costæ.

Occasionally an individual among these Fern Glen specimens occurs with what seem to be one or more strong, spine-like growths from the epitheca, but close observation shows these bodies to be not a part of the coral itself, but parasitic growths upon the coral, many or all of them being the bases of attachment of bryozoan colonies.

CYATHAXONIA MINOR n. sp.

Plate 10, figures 14-17

Description.—Corallum small, slender, curved or sometimes nearly straight, pointed below, tapering very gradually above, the upper half sometimes not increasing at all in diameter. Epitheca thin, without spines or tubercles, the surface marked by faint, longitudinal costæ which correspond in number with the septa; also by fine annular striæ which can only be detected with a magnifying glass, and by more or less inconspicuous annular wrinkles. Calyx of moderate depth, septa 26 to 29 in number. The central axis of the corallum occupied by a rather strong columella, which is extended upward in the bottom of the calyx.

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[4] *Zaphrentis tantilla* S. A. M.; Seventeenth Report of the Geological Survey of Indiana, p. 621, pl. 1, figs. 23-24.

The dimensions of a large individual are: Length along the convex side, 19 millimeters; diameter at the rim of the calyx, 3 millimeters.

Remarks.—This species may be distinguished from *C. arcuata,* with which it is associated, by its smaller size, its more slender form, its less number of septa, and often by its less curvature. In individuals of the two species of equal length the maximum diameter of *C. arcuata* is twice that of *C. minor.* In their surface markings the two species are essentially alike. The species is most closely allied to *C. tantilla* (S. A. M.), but it is usually more curved and has less strong longitudinal costæ.

AMPLEXUS RUGOSUS n. sp.

Plate 10, figures 22-25

Description.—Corallum simple, rather small, usually enlarging more or less abruptly at first and then less rapidly, nearly straight, moderately or rather strongly curved, or frequently geniculate, marked by many strong, exceedingly irregular annular wrinkles. Septa 18 to 21 in number, rather thick, extending nearly to the center of the corallum; tabulæ and dissepiments strongly developed, the lower portion of some individuals being so filled with calcareous matter as to be essentially solid.

The dimensions of an average individual are: Length, 28 millimeters; greatest diameter, 8 millimeters.

Remarks.—This species resembles *A. corniculum* S. A. M., from the Chouteau limestone at Sedalia, Missouri, but the septa are thicker and less numerous and extend more nearly to the center of the corallum.

AMPLEXUS BREVIS n. sp.

Plate 10, figures 26-29

Description.—Corallum rather small, curved, short, pointed below and expanding rapidly upward; marked by numerous strong, irregular, annular wrinkles. Calyx shallow, septa thick, 20 to 22 in number, not all of which reach the center of the corallum, some of them often curved. Tabulæ well developed in the upper portion of the corallum, the lower portion solidified by reason of the abundant secretion of calcareous matter.

The dimensions of an average individual are: Length along convex side, 24 millimeters; diameter at margin of calyx, 14 millimeters.

Remarks.—This species is not an entirely typical member of the genus *Amplexus,* because of its short and rapidly expanding form. In its rough, annular markings it resembles *A. rugosa* of this paper, but it differs from that species in its much shorter corallum.

ZAPHRENTIS CLIFFORDANA Milne-Edwards & Haime

Plate 10, figures 18-19

1851. *Zaphrentis cliffordana* Milne-Edwards and Haime, Monog. des Polyp. Foss., page 329, plate 3, figure 5.

1860. *Zaphrentis cliffordana* Milne-Edwards, Hist. Nat. Corr., volume 3, page 337.

1890. *Zaphrentis cliffordana ?* Worthen, Geological Survey of Illinois, volume 8, page 75, plate 10, figure 1 (not figure 1*b*).

Description.—Corallum simple, curved, horn-shaped, subcircular in cross-section, expanding somewhat regularly, the sides diverging from the apex at an angle of 35 to 45 degrees, subcarinate along the convex side toward the apex; the axis of the corallum describes a curve which approaches the quadrant of a circle, but which is somewhat more rapidly curved toward the apex. Surface marked by regular annular wrinkles of moderate strength and by almost obsolete longitudinal ribs which correspond in position with the septa. Calyx of moderate depth, with a broad base, the fossula of moderate size and depth adjacent to the shorter side of the corallum. Septa in a large individual with a calyx diameter of 20 millimeters, 35 in number without alternating smaller ones; another individual, with a calyx diameter of 13 millimeters, has 24 stronger septa with an equal number of small, low septal ridges alternating with them. The septa do not reach the center of the calyx, but leave a smooth, clear space in the bottom.

The dimensions of two individuals are: Length of the longer side of the corallum, 44 millimeters and 38 millimeters; length of shorter side of corallum, 19 millimeters and 19 millimeters; diameter of calyx, 20 millimeters and 13 millimeters.

Remarks.—Worthen has illustrated two specimens from the Kinderhook beds of Monroe county, Illinois, under the name *Z. cliffordana,* which could only have been found in the Fern Glen beds near Valmeyer. The two individuals are quite different in form and doubtless represent distinct species, both of which have been commonly met with in the recent collections from the Fern Glen beds at various localities. Only the smaller and more curved specimen illustrated by Worthen (figure 1) can be reasonably referred to *Z. cliffordana,* and it is with this coral that the specimens here described are identified. The character which seems to be most constant among the various individuals which have been studied is that of the curvature of the corallum and the comparatively smooth surface. The divergence of the sides of the corallum varies considerably in different individuals, so that the diameter of the rim of the calyx is variable, and the number of septa varies with the size of the calyx. In most of the specimens there is a distinct alternation of strong septa with much smaller septal ridges; but in one specimen which has been studied, a larger individual, with more rapidly expanding sides than usual, the alternating septal ridges are not present. The form of the calyx also varies in different individuals; it seems more commonly to be rather broad and flat in the bottom, with a rather wide area across which the inner ends of the septa do not pass, but in others it is deeper and more pointed in the bottom, with a smaller clear space between the inner ends of the septa. The somewhat subcarinate longitudinal ridge along the longer convex side of the corallum toward the apex is present upon the more typical individuals, but on others it is apparently absent.

The identity of this coral with the original *Z. cliffordana* described from the hills south of Louisville, Kentucky, seems to be probable, although an opportunity has not been afforded to compare typical examples from that region. The original figure of the species shows a specimen which is perhaps somewhat less curved at the apex than is usually the case in the Fern Glen specimens, and the rim of the calyx has been broken away so that the depth of the calyx can not be determined.

ZAPHRENTIS WORTHENI n. sp.

Plate 10, figures 20-21

1890. *Zaphrentis cliffordana* ? Worthen, Geological Survey of Illinois, volume 8, plate 10, figure 1*b* (not figure 1).

Description.—Corallum horn-shaped, subcircular in cross-section, moderately curved, the sides diverging at an angle of about 30 degrees. Surface rather smooth, marked by more or less infrequent annular wrinkles which are usually of small size. Rim of the calyx oblique; the calyx deep, contracted below, with a fossula of moderate depth and width toward the shorter, concave side of the corallum; the major septa 25 to 30 in number, their inner extremities extending toward the center of the floor of the calyx, but leaving a small central clear area; between the major septa and alternating with them are an equal number of much lower septa which are sometimes scarcely more than septal ridges.

The dimensions of two individuals are: Length of corallum on convex side, 54 millimeters and 40 millimeters; length of corallum on concave side, 30 millimeters and 17 millimeters; diameter of calyx at rim, 21 millimeters and 18 millimeters.

Remarks.—This species includes the straighter individual figured by Worthen under the name *Zaphrentis cliffordana.* It differs from the coral to which that name is here restricted in its much straighter and more elongate form, in the smaller angle of divergence of the sides of the corallum, and in the more oblique position of the calycinal rim.

BEAUMONTIA AMERICANA n. sp.

Plate 10, figures 3-4

Description.—Corallum compound, corallites prismatic, variable in size, the larger ones in the type specimen having a maximum diameter of about 8 millimeters and the smaller ones not exceeding 3 millimeters in diameter. Distally the corallites have some tendency to separate and to become more or less subcircular in cross-section. Epitheca marked by more or less irregular transverse wrinkles and sometimes by exceedingly indistinct longitudinal costæ. Internally the corallites are more or less filled with vesicular tissue usually consisting of incomplete tabulæ which are rarely or never horizontal in position. Septa obsolete.

Remarks.—The genus *Beaumontia* has not hitherto been recognized in the Mississippian faunas of America, although it is apparently not uncommon in England. The members of the genus resemble *Favosites* in habit of growth, but lack the perforations of the walls which are so characteristic of that genus. Of the species here described only a few fragmentary colonies have been observed, the dimensions of the largest one being about 38 millimeters by 22 millimeters; consequently the form of the complete colony is unknown.

FAVOSITES VALMEYERENSIS n. sp.

Plate 10, figures 1-2

Description.—Corallum forming more or less cylindrical masses slightly tapering above, growing upon crinoid stems. Corallites variable in size, attaining a maximum diameter of about 3 millimeters, the primary ones procumbent at first and then bending outward, the secondary ones occupying the angles between the primary ones and increasing rapidly in size. Walls of the corallites rather thin, pierced by numerous circular mural pores of moderate size. Endothecal structures not strongly developed, consisting of very thin more or less incomplete tabulæ, rarely extending more than half the diameter of the corallites.

The dimensions of a large corallum, but still incomplete, are: Length, 70 millimeters; greatest width, 29 millimeters.

Remarks.—This species is a close ally of *F. parasitica* Phillips, from the Carboniferous limestone of England. It differs from that species in the form of the corallum, which is more or less cylindrical, the British examples being subglobular. The larger specimen, which has been illustrated and whose dimensions are given above, is much larger than any of the others which have been observed, the colonies rarely growing to a greater width than 12 millimeters and a length of 30 millimeters.

CLADOCHONUS AMERICANUS n. sp.

Plate 10, figure 30

Description.—Corallum slender, erect, consisting of funnel-shaped corallites whose apertures are directed alternately in opposite directions. Each corallite consists of two regions, proximal and distal, the proximal portion being more slender, nearly straight or slightly curved, and increasing gradually in diameter; the distal region increases more abruptly in diameter to the aperture and curves laterally to such an extent that the plain of the aperture is approximately parallel with the axis of the corallum. On its upper side, the side of longest curvature, each corallite gives rise to a new corallite by budding from its distal region.

The dimensions of the type specimen are: Length of three successive corallites, 10 millimeters, 9 millimeters, and 9 millimeters; maximum diameter of aperture, 4.5 millimeters; minimum diameter of corallite at point of origin, 2 millimeters.

Remarks.—The genus *Cladochonus* has not previously been recognized in the Mississippian faunas of America, although it is represented by several species in the corresponding formations of Europe. It is not a common form in the Fern Glen fauna, the single specimen here described being all that has been observed by the writer. The genus occurs elsewhere in America—in the Chouteau limestone, where one or two undescribed species have been collected, and in the Burlington limestone, where it is represented by *Aulopora gracilis* Keyes. The genus *Cladochonus* differs from *Aulopora* in its erect habit of growth, it being attached only at its base or at more or less remote points.

MONILOPORA CRASSA (McCoy)

Plate 10, figures 31-33

1844. *Jania crassa* McCoy, Synopsis of Carboniferous Limestone Fossils of Ireland, page 197, plate 27, figure 4.
1847. *Cladochonus (Jania) crassus* McCoy, Annals and Magazine of Natural History, series 1, volume 20, page 227.
1849. *Cladochonus crassus* McCoy, Annals and Magazine of Natural History, series 2, volume 3, page 134.
1851. *Cladochonus crassus* McCoy, British Paleozoic Fossils, page 85.
1854. *Cladochonus crassus* Morris, Catalogue of British Fossils, second edition, page 44.

1869. *Cladochonus crassus* Rofe, Geological Magazine, volume 6, page 352, figures 2, 3, 4, 4*a*.

1879. *Monilopora crassa* Nich. & Eth., Jr., Geological Magazine, Decade 2, volume 6, page 293, plate 7, figures 2*a-f*.

1879. *Monilopora crassa* Nich., Palæozoic Tabulate Corals, page 223, figures 32*a-f*.

1899. *Monilopora crassa* Grabau, Proceedings of the Boston Society of Natural History, volume 28, page 410.

Description.—Corallum consisting of a tubular, stolon-like base attached to a crinoid stem, which at intervals gives origin to curved, conical corallites. The corallum commences as a ring of corallites with their connecting basal stolons encircling the crinoid column; adult colonies often leave their ring-like habit of growth in large measure and appear as confused aggregations of corallites surrounding the crinoid column. Not infrequently the entire coral becomes completely buried in the crinoid column by reason of the continued growth of the latter, so that only the rims of the calices project beyond the surface of the column. The individual corallites are conical in form and rather thick walled, with a diameter of from 2 millimeters to 6 millimeters at the rim, and are entirely free from tabulæ. The septa are all but obsolete, exceedingly faint septal ridges being discernible in only a few individuals.

Remarks.—This species seems to be entirely identical with the British form. It differs from *M. beecheri* Grabau, from the Crawfordsville crinoid beds, in its much smaller size, its shorter corallites, and in the greater regularity of the growth of its colonies in ring-like form surrounding the crinoid columns to which they are attached.

PALÆACIS DEPRESSUS (*Meek & Worthen*)

Plate 10, figures 5-7

1866. *Sphenopoterium enorme* var. *depressum* M. & W., Geological Survey of Illinois, volume 2, page 146, plate 14, figures 2*a*, 2*b*.

Description.—Corallum small, depressed, with a more or less truncate base; corallites one to four in number, with apertures usually nearly in a plane. Substance of the corallum apparently perforated in all directions by meandering and anastomosing pores or fine canals. External surface finely granular by reason of the presence of fine anastomosing furrows which cover the entire surface.

The dimensions of a corallum with three corallites is: Greatest width, 10 millimeters; height, 6.5 millimeters; diameter of corallites at apertures, 4.5 millimeters. The corallites of different individuals vary in width at their apertures from 3.5 millimeters to 5 millimeters.

Remarks.—This species was originally described as a variety of *P. enorme,* the type specimen being recorded as coming from "Salt Lick Point, Monroe county, Illinois." This locality is in the Mississippi River bluffs opposite Valmeyer and is one of those points where the Fern Glen formation is typically developed. It is possible that this form and *P. enorme* are only variations of a single species; but if that be the case, the form to which the name *depressus* has been applied is the normal form in the Fern Glen fauna at least. It occurs at all the principal Fern Glen localities, and scores of individuals have been observed, but no examples with the characters of the typical *P. enorme* have been seen associated with them. The form here described as *P. bifidus* is more nearly like the typical form of *P. enorme,* but even this seems to be specifically distinct.

There seems to be no valid reason for considering this little fossil as a sponge, as was done by Meek and Worthen. In their present condition of preservation the specimens are entirely similar to the associated undoubted corals, and therefore the original substance of the organism must have been the same, namely, calcium carbonate. If it was a sponge, it certainly was not a siliceous sponge. It seems altogether more probable that the creature was a coral of peculiar type. In its coralline relationships, however, the form seems to be unique, but perhaps no more so than the coralline forms of the genus *Monilopora.*

PALÆACIS BIFIDUS n. sp.

Plate 10, figures 8-11

Description.—Corallum cuneate at the base, two-celled, with the apertures divergent. The structure of the corallum and surface markings are as in *P. depressus.*

The dimensions of a large example are: Length, 13.5 millimeters; width, 6.5 millimeters; height, 11 millimeters; maximum diameter of corallites at aperture, 7 millimeters.

Remarks.—This form is much more rarely met with in the Fern Glen fauna than *P. depressus,* from which it is quite distinct by reason of its distinctly wedge-shaped form. Furthermore, no distinctly intermediate examples connecting the two forms have been observed. The species perhaps more closely approaches *P. enorme* in its general characters than it does *P. depressus,* but it differs from that species in the smaller number of corallites and in the more distinctly cuneate form of the corallum. In none of the individuals observed are there more than two cells, although it is possible that examples may be met with which will have a larger number.

ECHINODERMATA

CRINOIDEA

SYNBATHOCRINUS DENTATUS Owen & Shumard

Plate 11, figure 20

1852. *Synbathocrinus dentatus* O. & S., Journal of the Academy of Natural Sciences of Philadelphia (2), volume 2, page 93, plate 11, figures 7*a-b*.
1852. *Synbathocrinus dentatus* O. & S., Geological Report of Wisconsin, Iowa, and Minnesota, page 597, table 5B, figures 7*a-b*.
1894. *Synbathocrinus dentatus* Keyes, Missouri Geological Survey, volume 4, page 206, plate 25, figure 14.

Description.—Dorsal cup obconical, truncate at the base, wider than high, the sides nearly straight from the margin of the basal truncation to the tops of the radials, or diverging a little more rapidly above the tops of the basals. Basal plates a little less than one-half the total height of the dorsal cup; the basal truncation from two-fifths to one-third as wide as the dorsal cup at the top of the radials, somewhat excavated for the attachment of the column. Radial plates quadrangular, except the right postero-lateral one, wider than high; their distal faces marked by distinct articular grooves near the outer margin; the inner margin bears two tooth-like processes, divided by a narrow slit-like sinus, which extend upward within the bases of the arms. The left distal angle of the right postero-lateral radial is truncated for the support of the anal plate; surface of the plates smooth.

The dimensions of two dorsal cups are: Diameter at top of radials, 10.8 millimeters and 14.5 millimeters; height to base of arms, 7 millimeters and 8 millimeters; height to the tops of the distal processes of the radials, 10 millimeters and 12 millimeters.

Remarks.—Numerous examples of the dorsal cup of this species have been observed in the Fern Glen fauna, but no specimens preserving the arms have been seen. These dorsal cups are not different from similar specimens from the Burlington limestone. The species differs from other members of the genus in its somewhat higher dorsal cup and its nearly straight sides.

VASOCRINUS MACROPLEURUS (Hall)

Plate 11, figure 21

1861. *Cyathocrinus macropleurus* Hall, Description of New Species of Crinoids, page 5.
1861. *Cyathocrinus macropleurus* Hall, Journal of the Boston Society of Natural History, volume 7, page 295.
1879. *Vasocrinus macropleurus* W. & S., Revision of the Palæocrinoidea, part 1, page 96.

This species was described by Hall from incomplete specimens found in the Burlington limestone. It is not a common species in that formation and when found is almost always as detached plates. These plates are especially characterized by their deep undulations or corrugations and their thin margins, the extreme thinness of the margins being accountable for their usual separated condition when fossilized. In the Fern Glen beds the species is known from only two separate radial plates, the largest of which is here illustrated, which seem to differ in no essential respect from Burlington limestone specimens.

BARYCRINUS sp.

Plate 11, figure 22

This species is represented in the Fern Glen collections by a single specimen, which consists of the base and two radial plates. The underbasal plates are small, being wholly covered by the first column joint—an unusual condition in the genus. The basal plates are moderately tumid and are marked by fine granulations, which are arranged in a somewhat radial manner from the centers of the plates. The radial plates are more than twice as large as the basals, much broader than long, rather strongly convex, and with large arm facets.

The genus *Barycrinus* has not hitherto been recognized in beds older than the Lower Burlington limestone. This species is entirely different from any of those in the Lower Burlington and is probably new, although the specimen is too incomplete for description.

POTERIOCRINUS sp.

Plate 11, figure 24

This specimen is a small, complete dorsal cup with the base excavated for the attachment of the column. The width of the cup at the rim of the basal truncation is slightly more than 2 millimeters, the width at the top of the radials 7 millimeters, and the total height 5 millimeters. The sides from the basal truncation to the tops of the radials are slightly convex; all of the plates are smooth. The underbasals extend beyond the columnar facet for about one-half of their length; the basals are wider than high and are smaller than the radials. The arm facets occupy the entire width of the radials distally. Both an anal and a radianal plate of nearly equal size are present, as well as the first tube plate, which is slightly smaller.

So far as it is preserved, this little species is not unlike several members of the genus which have been described from the Kinderhook and

Burlington faunas, but in the absence of the arm characters it is not safe to identify it with any of them, nor to describe it as new.

CŒLIOCRINUS sp.

Plate 11, figure 27

This species is represented by the terminal portion of the ventral sack only, several specimens of which have been examined. Several species of the genus are known from the Lower Burlington limestone, but with the incomplete material available it is not possible to identify the Fern Glen specimens with either of them. It is possible that two species are represented among the Fern Glen specimens.

GRAPHIOCRINUS SAMPSONI n. sp.

Plate 11, figure 23

Description.—Calyx much depressed and very shallow, the stem facet situated in a deeply excavated depression. Underbasal plates small, completely covered by the column, not distinguishable in the type specimen. Basals longer than wide, pentagonal except the posterior one, their greatest width below the middle, just outside the margin of the excavation for the column, where their proximal portions are abruptly bent inward in a nearly vertical direction; distally the lateral boundaries of the plates are not straight, but contract more rapidly toward their extremities; posterior basal larger than the others, its distal extremity broadly truncated. Radial plates very thick, much wider than high, nearly horizontal in position, their articular faces nearly as large as the external surface, articular ridges well developed. Anal plate rather large, resting on the truncate posterior basal between the two postero-lateral radials, its distal extremity extending slightly above the articular surfaces of the radials. Radianal plate absent. External surface of the plates, except in the depression for the column, marked by scattered, low, but rather coarse tubercles. Arms and ventral surface unknown.

The dimensions of the type specimen are: Width, 12 millimeters; height of dorsal cup, 4.5 millimeters.

Remarks.—This species may be distinguished from other members of the genus by its much depressed calyx and the tubercular ornamentation of the plates. It is not closely related to any other species. The species has been named in honor of Mr F. A. Sampson, who has been the most successful collector of crinoids in the Fern Glen fauna.

PLATYCRINUS STELLATUS n. sp.

Plate 11, figures 13-14

Description.—Calyx rather small, about as wide as high. Basal plates not preserved in the type specimen. Radial plates quadrangular, height and width about equal, rather tumid below, the surface smooth, the arm facets very large, subcircular, reaching to below the middle of the plates. No brachial plates preserved. Ventral disk higher than the dorsal cup; above each radial are three plates arranged in arch-like manner above the arm opening; on the outer surface of these plates is a disk-like plate which projects out over the base of the arm, the whole combination of plates having the appearance of a strong, distally flattened node-like projection, with the arm opening piercing the calyx in the angle between the lower side of the node and the distal margin of the radial; these five projections above the five radials give to the calyx a distinctly stellate appearance when viewed from above. In each of the interradial areas between these radial nodes of the ventral disk, and resting upon the distal edges of the radials, is an interradial plate, those of four interradial spaces being small and narrow, the fifth, on the posterior side, being much larger. The central portion of the ventral disk is occupied by five rather large, somewhat tumid or nodose plates, one being nearly central, the other four being arranged around the central one on its anterior and lateral sides. Posterior to the central plate of the dome, and lying between it and the large posterior interradial plate, is the large anal opening which is directed upward.

The dimensions of the type specimen are: Height, exclusive of the basal plates, 13 millimeters; width of dorsal cup, 14 millimeters; width of calyx to the ends of the radial nodes of the ventral disk, 17.5 millimeters.

Remarks.—This species may be recognized by its strongly stellate appearance when viewed from above. Because of the position of the arm openings beneath and even in the lower side of the prominent radial nodes, the arms must have been more or less pendent when they were present.

PLATYCRINUS SPRINGERI n. sp.

Plate 11, figures 17-19

Description.—Calyx small, subglobular in form, wider than high. Base very shallow, saucer-shaped, the diameter of the basal disk a little more than one-half the diameter of the calyx between the arm bases. Radials wider than high, their surface gently convex, the facet for the attachment of the costal plates about one-half the total width of the plate. The first costal plate is axillary and extends horizontally from the calyx, with a distinct constriction at its proximal extremity, dorsally and laterally. The surface of the dorsal cup is marked with rounded tubercles; on the base they are arranged in a circle of ten around the stem facet, with usually an additional one or two in each distal angle of the disk; each radial plate carries five or six similar tubercles. Height of the ventral disk nearly equal to the dorsal cup. The first interradial plates between the arm bases are nearly vertical in position, eight-sided, and with two other plates, supported laterally and ventrally, occupy the entire space between the bases of the rays; in all except the posterior side, these plates are flat, but posteriorly the central plate bears a low, rounded, central node. Above the base of the rays the ventral plates are nearly uniform in size, slightly convex or obscurely nodose, and generally hexagonal in form, with a few usually inconspicuous smaller and less regular plates which are mostly situated just above the arm bases. The anal opening is eccentric and is directed ventrally.

The dimensions of the type specimen are: Height of calyx, 7 millimeters; width at top of radial plates, 9 millimeters.

Remarks.—In its tuberculate basal and radial plates this little crinoid resembles several species of *Platycrinus* from the Lower Burlington limestone, but it is clearly distinct from any of them. From the Kinderhook faunas no species with such distinctly tuberculate plates have been previously described.

The specific name has been given in honor of Mr Frank Springer, whose great familiarity with American crinoids has been most generously placed at the disposal of the writer in the identification of many of the obscure crinoidal fragments which occur so abundantly in the Fern Glen collections.

RHODOCRINUS PUNCTATUS n. sp.

Plate 11, figures 15-16

Description.—Calyx small, subglobular, contracted to the arm bases, with a deeply indented base. The plates marked by minute, closely arranged pits or punctæ, which can only be seen with a magnifying glass. Underbasals minute, included within the excavated base and covered by the column. Basal plates the largest plates of the calyx, their proximal portions abruptly incurved to form the sides of the basal excavation. Radial plates heptagonal; first costals very small, quadrangular; second costals axillary, pentagonal or hexagonal in form, as large or slightly larger than the first costals; distichals one in each series, their distal margins notched by the arm openings. First interbrachials a little smaller than the radials, followed by two somewhat smaller plates, and these by two other much smaller ones which extend up to the level of the arm openings. Arm openings two in each ray; arms not known. Ventral disk depressed convex, small, its diameter much less than the diameter of the calyx at its mid-height.

The dimensions of a nearly perfect calyx are: Height, 7.5 millimeters; diameter, 7.5 millimeters; diameter of ventral disk, 4.5 millimeters.

Remarks.—This species most closely resembles *R. wortheni,* from the Burlington limestone, but it has a more deeply excavated base, besides having the surface of the plates marked by the exceedingly fine pits or punctæ. It also resembles *R. watersianus* W. & Sp., from the Kinderhook at Le Grand, Iowa, but it may be distinguished by its more globular form and its proportionately much smaller ventral disk, the diameter of the circle formed by the arm openings in the Le Grand species being nearly or quite as great as that of the calyx at its mid-height, while in this species the circle has a much smaller diameter. The form of the first costal plates in these two species is also different, in the Fern Glen species this plate usually being quadrangular as it is in *R. wortheni,* although occasionally an additional face may be developed on one side, while in *R. watersianus* this plate is commonly hexagonal.

AGARICOCRINUS PRÆCURSOR Rowley

Plate 11, figures 7-12

1902. *Agaricocrinus præcursor* Rowley, American Geologist, volume 29, page 303, plate 18, figures 1-5.

Description.—Calyx subhemispherical or subglobose in form, dorsal cup flat or somewhat concave, ventral disk more or less dome-shaped. Basal plates small, often nearly covered by the column, the column facet either flush with the surface or slightly depressed. Radial plates smooth, flat or slightly convex, wider than long. First costals quadrangular, very short and broad; second costals much wider than long; in the two posterior lateral rays and sometimes in one of the anterior lateral rays this plate is axillary and supports two series of distichals which give origin to the arms; usually in all three anterior rays the first costal is followed by two other broad and short costals, the last one of which gives origin to an arm. Anal plate about equaling the radials in size, but proportionally longer and narrower, followed by three plates, each of which is nearly as large as the anal itself. The plates of the ventral disk exhibit considerable variation in the different individuals, but the central plate at the summit is always the largest plate of the entire calyx and is broadly and somewhat strongly convex; above the base of each ray are usually somewhat strongly nodose plates, which are more constantly present above the two postero-lateral rays and frequently consist of a series of large plates the upper one of which joins the large, central plate at the summit. The posterior interambulacral area is much larger than the others and is more or less strongly protuberant, the constituent plates being small and irregular; the anal opening is situated near the summit of this interambulacral area and is directed upward.

The dimensions of two individuals are: Total height of calyx, 16.5 millimeters and 14 millimeters; greatest width, 19.5 millimeters and 18 millimeters.

Remarks.—This species exhibits much variation in the convexity of the dorsal cup and in the prominence of the plates of the ventral disk, but may be distinguished from all other members of the genus by its small number of arm bases, there being usually seven, and among the individuals examined never more than eight. The protuberant posterior interambulacral region is also a constant characteristic.

The species was originally described from the typical Fern Glen beds at Fern Glen, Missouri.

LOBOCRINUS PISTILLIFORMIS (*M. & W.*)

Plate 11, figure 6

1861. *Actinocrinus pyriformis* var. *rudis* M. & W., Proceedings of the Academy of Natural Science of Philadelphia, page 131 (not *A. rudis* Hall, 1860).

1865. *Actinocrinus pistilliformis* M. & W., Proceedings of the Academy of Natural Science of Philadelphia, page 153.

1866. *Actinocrinus pistilliformis* M. & W., Geological Survey of Illinois, volume 2, page 151, plate 14, figure 8.

Description.—Calyx, exclusive of the anal tube, pyriform, being very narrow and apparently cylindrical from the base to the distal extremities of the costal plates, above which the distichals and palmers curve abruptly outward to the base of the arms, forming with the ventricose ventral disk a much expanded visceral cavity entirely above the costal plates. Basal and radial plates not known. First costals very small, a little wider than long, irregularly pentagonal in form so far as seen, one of the sides being much shorter than the others. Second costals axillary, as long as the first and nearly one-third wider; the only two visible in the type specimen are hexagonal in form, and each supports on its distal sloping sides two distichals of about its own size. Second distichals somewhat larger than the first, each of which supports two palmers, which in turn are succeeded by a second palmer, from which the free arms are given off. The two series of distichals and the four series of palmers in each ray are in contact laterally. Interbrachials two or three in each inter-ray, the first being of about the same size as the first costals and hexagonal or heptagonal in form; above this there are one or two small plates of variable size and form, over which the distichals and lateral series of palmers of the rays on each side are in contact all the way to the free arms. Anal plates unknown. Ventral disk hemispherical, composed of pentagonal, hexagonal, and heptagonal plates of nearly uniform size, each of which is provided with a central, spine-like tubercle. Anal tube central or nearly so. Arm openings twenty. Surface of plates smooth or obscurely granular; small pointed tubercles are also present on the costals, distichals, and first interbrachials.

The dimensions of the type specimen are: Diameter at arm bases, 25 millimeters; height from top of radial plates to the base of the anal tube, 26 millimeters; probable total height of calyx, exclusive of the anal tube, 37 millimeters; height of ventral disk, 15 millimeters.

Remarks.—This species was originally described by Meek and Worthen from the Fern Glen beds at Salt Lick point, near Valmeyer, Madison county, Illinois. It was later considered as a synonym of the Burlington *Lobocrinus pyriformis* (Shum.) by Wachsmuth and Springer,[5] but it seems to be sufficiently distinct from that form to be considered as a different species. It is especially distinguished from *L. pyriformis* by reason of the greater development of spine-like tubercles upon the plates of both the dorsal cup and the ventral disk and in the smaller number of interbrachial plates. The species has not been detected in the recent collections of Fern Glen material and it is known only from the original type specimen described and figured by Meek and Worthen.

ACTINOCRINUS RUBRA n. sp.

Plate 11, figures 4-5

Description.—Calyx about as wide as high, the arm openings situated midway between the top of the column and the base of the anal tube, the profile view of the specimen being subquadrangular. Dorsal cup obconical, the sides straight from the basals to the tops of the axillary costals, beyond which point the plates of the rays bend abruptly outward to a nearly horizontal position for a short distance. Basal plates rather small; radial plates the largest in the calyx, nodose, with raised, rounded, radiating ridges passing from the central node to each of the adjoining plates, the longitudinal ridges the most prominent and continued distally upon the brachial plates as distinct radial ridges; first costal plates smaller than the radials, crossed longitudinally by the strong, keel-like radial ridge, and with much weaker raised ridges passing laterally to the first interbrachial plates; second costal plates axillary, the strong radial ridge bifurcating at the center of the plate and the two distal divisions passing to the distichal plates; normally there is a single axillary distichal plate in each series, each of which supports two palmer plates which are the last brachial plates included in the calyx; the distichal and palmer plates are directed in a nearly horizontal direction, the interdistichal region in each ray being deeply depressed, with an interdistichal plate between the arm bases. Anal plate somewhat smaller than the radials; above the anal are two slightly nodose plates with raised radiating ridges passing to the adjoining plates; these two plates are followed by three nearly smooth plates, and these by others between the arm bases. First interradial plate of each area nodose, with raised, rounded, radiating ridges passing to each of the adjacent plates; these plates support two plates distally which are smooth and flat or with only faint radiating ridges. Ventral disk conical to the base of the anal tube, with the sides nearly straight; moderately depressed to the interradial spaces between the arm bases, the small plates flat or gently convex, the larger ones with low, broad, rounded nodes; three plates arranged in a triangle above the arm bases of each ray are the most conspicuously nodose. Base of the anal tube central. Arm openings four in each ray.

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[5] North American Crinoidea Camerata, p. 437.

The dimensions of the type specimen are: Height to base of anal tube, 31.5 millimeters; height of dorsal cup, 16 millimeters; diameter at base of arms, 32 millimeters.

Remarks.—This species is established upon a single, slightly distorted calyx, which is complete to the base of the anal tube. The specimen is slightly abnormal in the right anterior ray, in which there is but a single costal plate, but in this ray both the radial and the single costal are somewhat larger than are the corresponding plates in the other rays.

PHYSETOCRINUS SMALLEYI n. sp.

Plate 11, figures 1-3

Description.—Calyx wider than high, the ventral disk much higher than the dorsal cup, the depressions between the rays narrow. Dorsal cup broadly obconical to the top of the costal plates, beyond which the brachial plates bend outward in a nearly horizontal direction; costal plates strongly nodose, the nodes of successive plates connected more or less completely by a rather sharp radial ridge which is continued on the higher brachial plates of the calyx. Basal plates very short and forming a flat, disk-like base, or of moderate height; the radials about equal to the basals in size, with three nodes arranged horizontally at their middle line or with a single transverse node; first costals about equal to or a little smaller than the radials, hexagonal in outline, with a tendency to a trinodose ornamentation similar to that of the radials, the central node connected by a ridge with the central node of the radial; second costal pentagonal, axillary, strongly nodose, the node connected proximally with the central node of the first costal and distally with the distichal plates; distichals one in each series, broader than high; palmers with one or two plates in each series incorporated in the calyx; a deep V-shaped interdistichal groove marks the median line of each ray distally; arm openings four in each ray. Anal plate smaller than the radials, nodose, followed by two plates in the second series and three in the third, all of which are usually nodose. Interbrachial series consisting of three more or less strongly nodose plates, one below and two above, and these usually followed by two elongate plates between the bases of the rays. Ventral disk dome-shaped, much higher, sometimes twice as high as the dorsal cup, slightly depressed between the rays below, composed of numerous more or less nodose polygonal plates, those occupying the ambulacral regions being the most strongly nodose, some of the nodes almost assuming the form of short spines; anal opening almost central, with no anal tube.

The dimensions of a large individual are: Height, 27.5 millimeters; height of dorsal cup to arm openings, 10 millimeters; greatest width, 34 millimeters. The dimensions of a smaller individual are: Height, 21 millimeters; height of dorsal cup to arm openings, 7 millimeters; width, 24.5 millimeters.

Remarks.—This species is founded on the two nearly complete calyces whose dimensions are given above, both of which were collected by Mr F. A. Sampson. The two specimens differ somewhat in minor characters; the basals of the smaller individual are slightly higher and more nodose; the nodes on the radials and first costals are more distinctly tripartite in the larger specimen; the interradial depressions are relatively broader in the smaller specimen, a feature which may be due to the age of the individual.

At the request of Mr F. A. Sampson this species has been named in honor of Mrs C. T. Smalley, who has skillfully prepared many specimens of crinoids in his collection, including the ones here described.

MESPILOCRINUS sp.

Plate 11, figure 26

Several specimens of a tripartite crinoid base in the Fern Glen fauna have been recognized by Springer as the underbasals of a flexible crinoid, probably belonging to the genus Mespilocrinus. This identification is strengthened by the undoubted presence among the crinoid fragments of the peculiar column joints of this genus.

METICHTHYOCRINUS sp.

Plate 11, figure 25

A fragment of a dorsal cup, including the base and the radials, has been recognized by Springer as Metichthyocrinus. This genus has not hitherto been recognized in beds older than the Lower Burlington.

BLASTOIDEA

PENTREMITES DECUSSATUS Shumard

1857. *Pentremites decussatus* Shumard, Transactions of the Saint Louis Academy of Science, volume 1, page 242, plate 9, figures 6*a-b*.

Plate 11, figures 28-29

Description.—Body subovate in form, broadest below the middle. Basal plates very small, apparently forming a flat, horizontal disk. Radial plates very long, their proximal extremities inflected and probably being in nearly the same plane as the basal disk; the ambulacral sinuses very deep, their lower extremities extending nearly to the edge of the inflected, proximal portion; just below the very base of the sinuses the surface of each radial plate is produced into a low but distinct, pointed tubercle. Deltoid plates distinctly angular below, their height being about two-sevenths of the height of the lateral limbs of the radial plates. Ambulacral sinuses moderately wide, the width increasing toward the summit; the lancet plate entirely covered in the lower portion of the ambulacral area by the side plates, but toward the summit it is possibly exposed to a slight degree; the side plates are rather large, a little oblique in position, their inner extremities directed distally to a slight degree; those of the two series alternate in position; the median line of the ambulacra marked by a zigzag median furrow; the inner extremities of the side plates have a very narrow, slightly raised border, behind which is a depressed band marked by very fine transverse crenulations. The lateral surfaces of the radial and deltoid plates, from the base of the radial sinuses to their summit, are beautifully marked by fine, transverse costæ and by less strongly developed longitudinal lines, the longitudinal lines being strongest toward the base. The characters of the spiracles and the summit are unknown.

The dimensions of a nearly complete but badly crushed example are: Height, 20 millimeters; greatest width approximately, 15 millimeters.

Remarks.—This species was first described from detached radial plates found at "Button Mould Knob," south of Louisville, Kentucky. The Fern Glen examples agree exactly with the Kentucky specimens as they have been described and illustrated, the essential feature of the species, aside from its general form and proportions, being the peculiar ornamentation of the plates and the form of the side plates of the ambulacra, with their finely crenulated inner extremities. The Fern Glen specimens are all more or less fragmentary, the best example seen being one collected by Mr Sampson. This specimen is nearly complete, but is so crushed laterally as to destroy the characters of the base and the summit.

MOLLUSCOIDEA

BRYOZOA

In addition to the species here noted, the Fern Glen fauna contains several other forms of Bryozoa which are represented by material which is too imperfectly preserved for certain identification or for description. Several of them, however, are probably undescribed species.

FISTULIPORA FERNGLENENSIS n. sp.

Plate 15, figures 1-2

Description.—Zoarium consisting of more or less subcircular or elliptical disk-like bodies, or of irregular expansions, apparently free or attached only by the center of the disk, the under surface usually concave and covered by a wrinkled epitheca. Celluliferous surface convex in the subcircular examples, with a more or less irregular contour; monticules and maculæ ill defined or obsolete. Zoœcial apertures with a more or less regular quincunxial arrangement, more or less oblique, subelliptical in outline, with a broad and shallow but distinct lunarium on one of the longer sides of the ellipse; their longer diameter is .4 millimeter to .5 millimeter, the shorter being about three-fourths of the longer; the distances between the apertures is about one and one-half times the width of the apertures themselves. In tangential section the interzoœcial vesicles are seen to be polygonal in form and are usually two in number between adjacent zoœcia. In longitudinal section the zoœcia seem to lack diaphragms altogether, although they may rarely be present.

The dimensions of two disk-like zoaria are: Diameter, 26 millimeters and 45 millimeters; maximum thickness, 6 millimeters and 10 millimeters.

CHILOTRYPA AMERICANA S. A. M.

Plate 15, figure 3

1881. *Trematopora americana* S. A. M., Journal of the Cincinnati Society of Natural History, volume 4, page 312, plate 7, figures 5-5*a*.

Description.—Zoarium consisting of more or less irregular, subcylindrical branches, 2 to 10 millimeters in diameter, the smaller ones sometimes solid, the larger ones with an axial cavity. Zoœcial apertures arranged irregularly, ovate in outline, their margins slightly elevated in a thickened lip; lunarium usually rather obscure, the intervals between the apertures three or four times the width of the apertures themselves. Surface of the zoarium elevated at intervals in rather large, undefined monticules, upon which the zoœcia are more widely scattered.

Remarks.—Miller's species, *Trematopora americana,* was described without mention of the internal characters, and the present Fern Glen examples are identified with it on the strength of the external features alone. In these characters the Fern Glen specimens agree very closely with Miller's figures and description. The species is clearly not a member of the genus *Trematopora.* It is one of the Fistuliporidæ and seems to correspond in all essential features with the genus *Chilotrypa.*

CYSTODICTYA LINEATA Ulrich

Plate 15, figure 4

1884. *Cystodictya lineata* Ulrich, Journal of the Cincinnati Society of Natural History, volume 7, page 37, place 2, figures 4-4*c*.

Description.—Zoarium bifoliate, consisting of strongly compressed, sharp-edged, bifurcating branches. Surface of each face of the branches a little convex, with low, rounded, longitudinal ridges, between which the zoœcial apertures are arranged in from seven to nine longitudinal lines; transversely the zoœcial apertures are arranged in more or less regular oblique rows; the longitudinal ridges are most conspicuous and most continuous in the central portion of the branches; laterally they become more or less discontinuous and consist rather of a series of depressed nodes upon the inner slopes of which are located the zoœcial apertures; outside of the outermost zoœcia is a narrow, smooth, or finely striated, non-poriferous margin; zoœcia with distinct lateral lunaria, which give to the apertures a depressed pyriform outline; on either side of the median line of the branches the lunaria are situated on the outer lateral margins of the zoœcial apertures, and the apertures themselves are directed with a slight obliquity toward the median line.

The dimensions of an average example are: Width of branches of zoarium, 4 to 5 millimeters; greatest thickness of branches, .75 millimeter to 1 millimeter; number of zoœcial apertures in the space of 2 millimeters longitudinally, 3 to 4; number of zoœcial apertures in the space of 2 millimeters transversely, about 4.

Remarks.—This species is one of the less common bryozoa in the Fern Glen fauna. The species is usually identified from a somewhat higher horizon, being an abundant form in the Upper Keokuk, Salem, and Saint Louis faunas, but the Fern Glen examples agree more closely with the original description of the species than do those commonly so identified from the Salem and Saint Louis.

EVACTINOPORA SEXRADIATA M. & W.

Plate 15, figures 5-16

1868. *Evactinopora sexradiata* Meek and Worthen, Geological Survey of Illinois, volume 3, page 502, plate 17, figure 3.

1890. *Evactinopora sexradiata* Ulrich, Geological Survey of Illinois, volume 8, page 510, plate 73, figures 2-2*b*.

1894. *Evactinopora sexradiata* Keyes, Missouri Geological Survey, volume 5, page 18.

Description.—Zoarium free, with a stellate base, which is the only portion yet detected in the Fern Glen collections. Base with from four to nine rays, six being the most usual number; the rays are compressed laterally, their lower edge describing a convex curve from the center of the base to the tips of the rays; sinuses between the rays more or less variable in depth, the central disk varying from one-fourth to one-half the total diameter of the base. In the center of the lower side of the disk a small polygonal area is often present, outlined by faint ridges, the angles of the polygon being equal in number to and opposite the rays, and from each angle a similar ridge passes to the extremity of the ray along its median line; the size of the central polygon varies with the relative size of the disk as compared with the total diameter of the base; in other individuals the ridges marking the rays join at the center of the disk in a regular or irregular manner without the polygonal inclosed area.

The diameter of an average sized individual is 11.5 millimeters; the diameter of the largest example observed is 20 millimeters.

Remarks.—This species of *Evactinopora* is one of the commonest and most characteristic members of the Fern Glen fauna and is highly variable in form. Among 146 bases preserving all of the rays, 3 have four rays, 39 have five rays, 44 have six rays, 37 have seven rays, 18 have eight rays, and 5 have nine rays. Other characters in which the specimens vary are the relative size of the central disk and the thickness of the rays themselves. The combined characters of all of these examples seem almost to include the characters of the three species, *E. sexradiata* M. & W., *E. quinqueradiata* Ulr., and *E. radiata* M. & W., but Ulrich's figures of *E. sexradiata* best exhibit the most usual features of the species. *E. quinqueradiata,* as interpreted by Ulrich, has relatively longer and more slender rays, and *E. radiata,* as interpreted by the same author, has a much larger disk and is much higher in proportion to the diameter of the base.

BRACHIOPODA

CRANIA MISSOURIENSIS *n. sp.*

Plate 12, figure 1

Description.—Shell rather large, subcircular in outline. The dorsal valve depressed convex, the apex rather obscure and situated excentrically about one-third the length of the shell from the anterior margin. Surface of the shell marked by rather fine but more or less irregular and uneven concentric markings.

The dimensions of the type specimen are: Length, 17 millimeters; width, 17 millimeters.

Remarks.—The type of this species has grown upon the interior of the pedicle valve of a *Productus.* The central portion of the shell is depressed convex, but toward the margins it becomes concave, because of the strongly concave surface to which it is attached. Attached to some other flatter surface the shell would doubtless be depressed convex throughout. The species seems to be distinct from any of the described forms, although one or two Lower Mississippian species have been so briefly described without illustrations that they can not be recognized except through a study of the type specimens.

LEPTÆNA RHOMBOIDALIS (*Wilckens*)

Plate 12, figures 2-3

1821. *Anomites rhomboidalis* Wahlenberg, Acta. Society of Upsala, volume 3, page 65.

1836. *Producta analoga* Phillips, Geology of Yorkshire, volume 2, page 215, plate 7, figure 10.

1859. *Strophomena rhomboidalis* var. *analoga* Davidson, British Fossil Brachiopoda, volume 2, page 119, plate 28, figures 1-2.
1877. *Strophomena rhomboidalis* White, U. S. Geographic Survey West of the 100th Meridian, volume 4, page 85, plate 5, figure 5.
1877. *Strophomena rhomboidalis* Hall & Whitf., U. S. Geological Explorations of the 40th Parallel, volume 4, page 253, plate 4, figure 4.
1888. *Strophomena rhomboidalis* Herrick, Bulletin of the Dennison University, volume 4, plate 9, figure 6.
1889. *Strophomena rhomboidalis* Herrick, American Geologist, volume 3, plate 4, figure 6.
1892. *Leptœna rhomboidalis* Hall & Clarke, Introduction to the Study of the Brachiopoda, part 1, plate 13, figure 9.
1892. *Leptœna rhomboidalis* Hall & Clarke, Paleontology of New York, volume 8, part 1, plate 8, figures 30-31; plate 20, figure 24.
1894. *Plectambonites rhomboidalis* Keyes, Missouri Geological Survey, volume 5, page 70, plate 39, figure 6.
1895. *Strophomena rhomboidalis* Herrick, Geological Survey of Ohio, volume 7, plate 20, figure 6.

Description.—Shell transversely subsemicircular or subquadrate in outline, the hinge line straight, equaling the greatest width of the shell, the valves geniculate anteriorly and laterally. Pedicle valve slightly convex near the beak; beyond the convex area it becomes flattened to the line of geniculation, where it is abruptly bent toward the opposite valve at nearly a right angle; on the flattened portion of the valve there are present a variable number of concentric undulations or wrinkles which are sometimes discontinuous and which bend outward toward the cardinal extremities as they approach the cardinal margin; beak small, not incurved, with a minute perforation which is sometimes obsolete or obscure; cardinal area rather narrow, with a wide delthyrium which is nearly closed by the cardinal process of the opposite valve when the two valves are in articulation, the deltidium being very small and restricted to the apex of the delthyrium. Brachial valve concave, the posterior portion flattened, bent abruptly upward toward the margin to conform with the pedicle valve; flattened portion of the valve marked by concentric wrinkles or undulations similar to those of the pedicle valve, the cardinal area narrower than that of the pedicle valve. Both valves marked, in addition to the concentric wrinkles, with very fine radiating striæ.

The dimensions of a specimen of average size are: Length, 20 millimeters; width, 28 millimeters.

Remarks.—This is a rather common member of the Fern Glen fauna and does not differ essentially from members of this long range species from other horizons and localities.

ORTHOTHETES RUBRA n. sp.

Plate 12, figures 4-5

Description.—Shell of medium size when full grown, wider than long, the hinge line straight and slightly shorter than the greatest width of the shell; lateral margins slightly convex posteriorly, becoming more strongly curved in front and rounding regularly into the anterior margin, which is nearly straight in the middle half of the shell; shell substance rather thick. Pedicle valve depressed convex, most prominent toward the beak, the surface sloping gently toward the front and a little more steeply toward the cardinal extremities with a slightly convex curve; cardinal area rather low, apparently flat, but not well shown in the type specimen. Brachial valve about as convex as the pedicle, slightly compressed toward the cardinal extremities. Surface of both valves marked by fine radiating costæ, some of which are slightly larger than the others; the costæ increase by intercalation and about three occupy the space of one millimeter. The surface is also marked by fine concentric lines, which are apparently more conspicuous toward the cardinal extremities, on which parts of the shell the radiating costæ appear to be minutely serrate by reason of the crossing of the concentric lines. A few more or less inconspicuous lines of growth occur upon the main body of the shell, but in old examples the growth lines become much crowded toward the margin and the shell thickened.

The dimensions of a nearly complete example are: Length, 25 millimeters; width, 36 millimeters; length of hinge line, 32 millimeters; thickness, estimated, 10 millimeters.

Remarks.—This species is rather rare in the fauna. It resembles *O. lens* (White), from the Louisiana limestone, but it grows to a much larger size, is proportionally broader, and is marked by somewhat finer radiating costæ than that species. Some of the smaller and immature examples are of about the average size of the full grown specimens of *O. lens*, but they may be distinguished from that species by their form and costæ.

ORTHOTHETES ? sp.

A single imperfect internal cast of the brachial valve of a large *Orthothetes* or *Derbya*-like shell has been observed in the Fern Glen fauna which is too incomplete for identification. When complete the shell must have had a length of 40 millimeters and a width of about 55 millimeters. It has a broad and strong cardinal process and was marked by rather strong concentric wrinkles.

RHIPIDOMELLA MICHELINIA L'Eveille

Plate 12, figures 8-10

1835. *Orthis michelinia* L'Eveille, Memoires de la Société Geologique de France, volume 2, page 39, plate 2, figures 14-17.

1858. *Orthis michelini* var. *burlingtonensis* Hall, Geology of Iowa, volume 1, part 2, page 596, plate 12, figures 4*a-b*.

1858. *Orthis michelinia* Davidson, British Fossil Brachiopoda, volume 2, page 132, plate 30, figures 6-12.

1892. *Orthis* (*Rhipidomella*) *burlingtonensis* Hall & Clarke, Paleontology of New York, volume 8, part 1, plate 6A, figure 13; plate 20, figures 5-6.

1894. *Orthis burlingtonensis* Keyes, Missouri Geological Survey, volume 5, page 63, plate 38, figure 7.

1899. *Rhipidomella burlingtonensis* Weller, Transactions of the Saint Louis Academy of Science, volume 9, page 15, plate 4, figure 13.

1901. *Rhipidomella burlingtonensis* Weller, Transactions of the Saint Louis Academy of Science, volume 11, pages 150 and 181, plate 12, figure 3, and plate 16, figure 6.

Description.—Shell lenticular in form, subcircular or subovate in outline, as wide as or a little wider than long, the greatest width at or in front of the middle, hinge line short, one-third or less than one-third the width of the shell. Pedicle valve depressed convex, most prominent on the umbo, the surface sloping rather abruptly to the cardinal margin with a slightly concave curvature, and gently to the lateral and anterior margins with a moderately convex curvature; the median portion of the valve either not differentiated from the lateral surfaces or flattened or slightly depressed in a broad, shallow, ill defined sinus in the anterior half; in the posterior half of the valve the median portion is somewhat marked by a slight, ill defined median elevation; cardinal area small, a little concave, the delthyrium rather broad. Brachial valve with a convexity about equaling that of the pedicle valve; convexity nearly uniform, but sloping a little more abruptly to the cardinal margins, the median portion of the valve depressed in a rather broad, shallow, ill defined sinus which extends nearly or quite to the beak. Surface of both valves marked by fine, rounded, radiating costæ, which increase by bifurcation and intercalation, about two or three costæ occupying the space of one millimeter; the surface also marked by concentric lines of growth which vary in strength and distribution in different individuals.

The dimensions of one of the most complete individuals observed in the Fern Glen fauna are: Length, 20 millimeters; width, 20.5 millimeters; thickness, 9 millimeters.

Remarks.—This is one of the most abundant species in the Fern Glen fauna, but it is of smaller size than usual for the species. A length of

12 millimeters is perhaps an average size for the Fern Glen examples, although some of the larger ones grow to be 25 millimeters or more in length. No specific differences can be detected, however, between the larger and smaller individuals associated in this fauna, nor between these and members of the same species elsewhere. The American examples of this shell have usually been considered as either varietally or specifically distinct from the European *R. michelinia,* but a careful examination of many specimens from various localities in both America and Europe has failed to bring out constant characters of any sort which can be used to distinguish the European from the American examples.

The shell which Miller has called *Orthis dalyana,* from Lake valley, New Mexico, is perhaps identical with this *Rhipidomella michelinia* of the Mississippi valley; it is certainly a member of the same genus, and if not identical is at least a closely allied species.

SCHIZOPHORIA SWALLOVI Hall

Plate 12, figures 6-7

1848. *Orthis resupinata* Christy, Letters on Geology, plate 3, figures 1-2.
1858. *Orthis swallovi* Hall, Geology of Iowa, volume 1, part 2, page 597, plate 12, figures 5*a-b*.
1892. *Orthis* (*Schizophoria*) *swallovi* Hall & Clarke, Paleontology of New York, volume 8, part 1, plate 6, figures 23-24.
1894. *Orthis swallovi* Keyes, Missouri Geological Survey, volume 5, page 63, plate 38, figure 5.
1899. *Schizophoria swallovi* Weller, Transactions of the Saint Louis Academy of Science, volume 9, page 13, plate 4, figure 7.
1900. *Schizophoria swallovi* Weller, Transactions of the Saint Louis Academy of Science, volume 10, page 66, plate 1, figures 11-13.

Description.—Shell biconvex, resupinate, transversely subelliptical in outline, the hinge line shorter than the greatest width of the shell, the cardinal extremities rounded. Pedicle valve depressed convex, most prominent on the umbo, the surface sloping rather abruptly to the cardinal margin and more gently toward the lateral and antero-lateral margins, the mesial portion flattened toward the front and sometimes, in the larger individuals, depressed into a more or less conspicuous mesial sinus which is ill defined laterally; beak rather small, moderately incurved; cardinal margin of moderate height, sloping slightly backward from the plane of the valve and gently arched to the point of the beak, the delthyrium about as wide as high. Brachial valve much more strongly convex than the pedicle, most prominent near the middle, the surface sloping rather abruptly to all sides, sometimes with an ill defined mesial fold toward the front, the umbo prominent, produced backward beyond the hinge line, the beak more strongly incurved than that of the opposite valve, the cardinal area about one-half the width of that of the pedicle valve, arched and directed posteriorly and toward the beak of the pedicle valve. Surface of both valves marked by small, rounded, radiating costæ, about three of which occupy the space of one millimeter; the costæ are separated by rounded furrows about equal in width to the costæ themselves; upon the pedicle valve the costæ increase by bifurcation, and on the brachial valve by implantation; the surface is also marked by more or less crowded, subimbricating lines of growth.

The dimensions of a rather large individual are: Length, 30 millimeters; width, 36.5 millimeters; thickness, 23 millimeters; length of hinge line, 20 millimeters; height of cardinal area, 4 millimeters.

Remarks.—This species in the Fern Glen fauna does not attain so large a size as it does in the Burlington limestone, where examples not infrequently exceed 50 millimeters in width, but in all other respects the Fern Glen examples are essentially identical with specimens from the higher formation. The species should probably not be considered as distinct from the European *S. resupinata* of the mountain limestone, but until a careful comparative study of the American and European forms can be made it is perhaps not advisable to drop the present name. The species is a close ally of the Devonian *S. striatula;* it differs from that species especially in the larger size to which it grows and in the much less development of the mesial sinus of the pedicle valve.

CHONETES ILLINOISENSIS Worthen

Plate 12, figure 11.

1858. *Chonetes logani* Hall, Geological Survey of Iowa, volume 1, part 2, page 589, plate 12, figures 1-2 (not *C. logani* N. & P., 1855).

1860. *Chonetes illinoisensis* Worthen, Transactions of the Saint Louis Academy of Science, volume 1, page 571.

1868. *Chonetes illinoisensis* M. & W., Geological Survey of Illinois, volume 3, page 505, plate 15, figure 8.

Description.—Shell concavo-convex, the length from .6 to .7 of the width, hinge line usually a little shorter than the total width of the shell, but sometimes equaling the width. Lateral margins of the shell nearly straight or slightly convex posteriorly, directed at nearly a right angle to the cardinal line, more strongly curved anteriorly and passing with a regular arcuate curvature into the anterior margin, which is often nearly straight for a short distance in its central part. Pedicle valve depressed convex, somewhat compressed toward the cardinal extremities, flattened along the mesial region and often depressed in a shallow, ill defined mesial sinus. Brachial valve concave, following rather closely the curvature of the pedicle valve; in none of the Fern Glen examples have the cardinal spines been observed. Surface of both valves marked by fine, nearly regular, radiating costæ, which increase by bifurcation on the pedicle valve and by intercalation on the brachial valve; the total number of costæ vary from 175 to 225, according to the size of the individuals, but there are constantly about 6 costæ in the space of 1 millimeter.

The dimensions of two individuals, the larger of which is slightly flattened, are: Length, 13 millimeters and 12 millimeters; width, 21 millimeters and 17.5 millimeters; convexity, 3.5 millimeters and 4.5 millimeters.

Remarks.—There has been some confusion in the interpretation of this species as it occurs in the Kinderhook and Osage faunas of the Mississippi valley and errors have sometimes been made in the identification of the Kinderhook specimens. In its typical form the species occurs in the Burlington limestone, sometimes in enormous numbers, these specimens usually having a width of about 15 millimeters or a little more. Where the species occurs more sparingly it often grows to a larger size, sometimes attaining a width of 22 millimeters. In Worthen's description of the species the number of costæ are said to be 100 to 120 or more in number, but this number is understated, as about 170 to 190 costæ are the usual number upon shells of average size, but upon larger individuals they increase to 225 or more. The actual number of costæ varies with the size of the individual, but the size of the costæ is a much more constant feature, there being about six in the space of one millimeter, whether the shell be large or small. In Meek and Worthen's description of the species 12 to 14 costæ are said to be present in .10 inch, which would be nearly the number observed on the specimens studied by the writer; 6 costæ in one millimeter would be equivalent to 15 in .10 inch. Winchell's *C. multicosta*, with "180-200 fine, subflexuous, radiating striæ," is doubtless synonymous with *C. illinoisensis*, and the species would probably never have been described if Hall or Meek and Worthen had stated accurately the number of costæ in that species.

The specimens in the Chonopectus fauna at Burlington, Iowa, which were referred to *C. illinoisensis* by the writer,[6] are probably a distinct species, characterized by its coarser markings, the costæ usually being about 110 to 120 in number on an average specimen, about 4 of which occupy the space of one millimeter. The statement in that place that the shells were marked by 120 to 200 costæ was based upon observations made in part upon the Burlington limestone specimens.

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[6] Transactions of the Saint Louis Academy of Science, vol. 10, p. 67, pl. 1, fig. 14.

Chonetes shumardiana De Kon., with which *C. illinoisensis* has sometimes been compared, has not come under the observation of the writer, but it is a much more finely marked species, with about 12 costæ in the space of one millimeter.

The specimens in the Fern Glen fauna which are identified as *C. illinoisensis* are usually somewhat larger than the average sized specimens in the Burlington limestone, although none of them are as large as the largest of the Burlington specimens. They agree closely with the Burlington shells in the size and number of costæ and in the general outline of the shell, although they sometimes appear to be proportionally a little wider because of the slight crushing of the shell which has often taken place.

CHONETES LOGANI N. & P.

Plate 12, figures 12-13

1855. *Chonetes logani* N. & P., Journal of the Academy of Natural Science of Philadelphia (2), volume 3, page 30, plate 2, figures 12*a*-*b*.
1892. *Chonetes logani* H. & C., Paleontology of New York, volume 8, part 1, plate 16, figure 25.

Description.—Shell small, wider than long, the greatest width along the hinge line, cardinal extremities angular. Pedicle valve strongly convex or inflated in the central portion, compressed toward the cardinal angles to form small auriculations, without mesial sinus; surface marked by from 35 to 45 rounded, bifurcating costæ crossed by raised, concentric markings which are entirely or nearly obsolete in the furrows between the ribs; cardinal area narrow, the cardinal margin marked by two or sometimes three spine bases. Brachial valve deeply concave, following closely the curvature of the opposite valve.

The dimensions of an average example are: Width, 11 millimeters; length, 7.5 millimeters; convexity, 4 millimeters.

Remarks.—This is not a common species in the Fern Glen fauna, but most of the specimens observed are more or less nearly complete. The species can be easily distinguished from the associated *C. illinoisensis* by reason of its smaller size, its greater convexity, and its stronger, rugose, radiating costæ.

PRODUCTUS FERNGLENENSIS n. sp.

Plate 12, figures 14-17

Description.—Shell of medium size, a little wider than long, except in very old and much produced individuals, the hinge line a little shorter than the greatest width of the shell, cardinal extremities with small auriculations. Pedicle valve gibbous, beak incurved, the median portion of the valve broadly flattened or depressed in a shallow, more or less broad, rather ill defined sinus, the sides abruptly rounding and dropping away almost vertically to the lateral and cardinal margins. Surface of the valve marked by moderately coarse, rounded, longitudinal costæ, and on the posterior side by concentric wrinkles, giving to the shell the typical markings of the semireticulate section of the genus; on its anterior half the shell is marked by the more or less remotely scattered bases of moderately coarse spines, and on the anterior side of each of these spine bases the longitudinal costæ of the shell are somewhat fasciculate. Brachial valve gently concave posteriorly, becoming flattened toward the cardinal extremities, rather abruptly curved toward the front to conform with the curvature of the opposite valve, elevated along the median line in a low rounded fold. Surface marked by longitudinal costæ similar to those of the pedicle valve, and upon the flatter portion of the valve by concentric wrinkles about equal in strength to the longitudinal costæ.

The dimensions of a rather small individual are: Width, 31 millimeters; length, 28 millimeters; length of hinge line, 25 millimeters; length of shell along the median line, following the curvature of the surface, 50 millimeters.

Remarks.—This species approaches *P. burlingtonensis* in its characters and has usually been so identified. It differs from that species, however, in the lower curvature of the pedicle valve, in the less conspicuous mesial sinus of the same valve, which is broader and shallower in this species and sometimes even obsolete; it also differs in the fasciculation of the longitudinal plications in their extension anteriorly from the spine bases. The species resembles *P. costatus* almost more closely than it does *P. burlingtonensis,* but may be distinguished by its less conspicuous auriculations and by the absence of the well defined oblique row of spines which extend from the beak anteriorly at the inner margin of the auriculations of *P. costatus,* and usually by the less strongly marked surface markings of the shell.

PRODUCTUS SAMPSONI n. sp.

Plate 12, figures 18-22

Description.—Shell small, as long or longer than wide, rarely a little wider than long, the hinge line shorter than the greatest width of the shell, auriculations small or almost obsolete. Pedicle valve strongly arched, the beak small and strongly incurved beyond the cardinal line, the umbo prominent and projecting considerably back of the hinge line, the median line of the valve prominent from beak to front without median sinus, the sides curving at first more gently and then abruptly to the lateral and cardinal margins. Brachial valve deeply concave, following rather closely the curvature of the opposite valve and allowing but a small space for the visceral parts of the animal. Surface of both valves marked by rather fine, depressed convex, bifurcating, longitudinal costæ which are separated by grooves narrower than the costæ themselves; surface also marked by irregular, concentric, lamellose lines of growth which become more strongly marked on somewhat worn specimens. Spine bases few in number, rather stout, limited to the auricular and lateral portions of the pedicle valve.

The dimensions of two individuals are: Length, 12 millimeters and 13.5 millimeters; width, 11.5 millimeters and 14 millimeters; convexity of pedicle valve, 6 millimeters and 6 millimeters.

Remarks.—In its general form and size this species has some resemblance to the Upper Devonian *Productella hallana* Walc., but it is usually a narrower shell, more prominent along the median line of the pedicle valve, and with similar surface markings upon each valve. There is no other species in the Kinderhook faunas which it at all resembles.

CAMAROPHORIA BISINUATA (*Rowley*) ?

1900. *Seminula bisinuata* Rowley, American Geologist, volume 25, page 263, plate 5, figures 21-24.

Rowley has described a small shell from the white cherts of Louisiana, Missouri, as *Seminula bisinuata*. Specimens of the species from southwestern Missouri in the collection of Walker Museum, some of which are internal casts, demonstrate the presence of a distinct median septum in each valve, with a well defined spondylium in the pedicle valve. With such characters the shell can not be placed in the genus *Seminula*, and it seems more properly to belong to *Camarophoria*. In the Fern Glen fauna a single example of a much crushed, smooth, rostrate brachiopod shell, with a distinct and strong median fold and sinus in the anterior half of the shell, is placed provisionally in this species. The presence of a median septum is clearly shown in the pedicle valve, and it is probably accompanied with a spondylium; the median septum of the brachial valve is not shown. Before distortion the shell apparently has a length and width of about 10 millimeters each.

CAMAROTŒCHIA PERSINUATA (*Winchell*)

Plate 12, figures 24-25

1865. *Rhynchonella persinuata* Winchell, Proceedings of the Academy of Natural Science of Philadelphia, page 121.

1901. *Camarotœchia persinuata* Weller, Transactions of the Academy of Sciences of Saint Louis, volume 11, page 197, plate 19, figure 5.

Description.—Shell of medium size, broadly subovate in outline, broader than long, the greatest width at or in front of the middle. Pedicle valve depressed convex in the umbonal region, the surface rounding rather abruptly to the postero-lateral margins, the median portion depressed abruptly anteriorly in a broad, nearly flat mesial sinus which is produced into a broad lingual extension in front at nearly a right angle to the plane of the valve. Brachial valve subpyramidal in form, most prominent near the anterior margin, the surface rounding more abruptly to the antero-lateral margins. Surface of each valve marked by simple, angular or subangular plications, of which usually seven occupy the mesial sinus and eight the fold and about eight or nine each lateral slope of each valve; around the anterior and lateral margins the grooves between the plications are produced into extended, acutely angular serrations which fit into corresponding angular notches in the ribs of the opposite valve.

The dimensions of a crushed example of this species are: Length, 16 millimeters; width, 17.5 millimeters.

Remarks.—This species is represented in the Fern Glen collections, which have been available for study, only by much crushed individuals. These specimens, however, are clearly identical with this species, which was described by Winchell from the highest Kinderhook bed at Burlington, Iowa, and a part of the characters mentioned in the above description have been taken from an excellent example from Burlington.

The shell from Lake valley, New Mexico, which has been described by Miller as *Camarophoria occidentalis*, is similar to the present species and is, perhaps, identical with it. In neither the description nor the illustrations of the New Mexican shell are the essential features of the genus *Camarophoria* indicated, and there need be no hesitation in considering it as congeneric with this Fern Glen shell, even if it is not the same species.

SPIRIFER VERNONENSIS *Swallow*

Plate 13, figures 3-8

1860. *Spirifer vernonensis* Swallow, Transactions of the Academy of Science of Saint Louis, volume 1, page 644.

Description.—Shell of medium size, subsemicircular in outline, wider than long, the greatest width along the hinge line, cardinal extremities angular or a little rounded. Pedicle valve strongly convex, strongly arched from beak to front, the median line often describing nearly a semicircle; the beak rather small, pointed, and strongly incurved; cardinal area of moderate height, concave, its ventral margin sharply defined, sloping laterally from each side of the beak to the hinge line at the cardinal extremities, the slope becoming more abrupt as it approaches the end of the hinge line; mesial sinus deep, subangular, originating at the point of the beak and widening rapidly to the front, where its anterior portion is often produced into a lingual extension; it is smooth at the beak, but anteriorly it is marked by a single median plication and by eight or ten others which originate through the successive bifurcation of the lateral bounding plications; lateral slopes convex except along the cardinal margin and toward the cardinal extremities, where they become slightly concave. Brachial valve nearly as convex as the pedicle, most elevated at the anterior extremity of the mesial fold; beak small, strongly incurved, cardinal area narrow, becoming attenuate toward the cardinal extremities; mesial fold depressed in the posterior half of the valve, frequently becoming strongly elevated, subcarinate and sometimes slightly recurved toward the anterior margin; it is smooth at the beak, but marked anteriorly by eight or ten plications which originate through the successive bifurcation of the initial median rib; lateral slopes convex except toward the cardinal extremities, where they become somewhat flattened. Lateral slopes of both valves marked by mostly simple, rarely bifurcating, rounded plications, fifteen to twenty-two being present upon each side of the fold and sinus, those toward the cardinal border becoming successively smaller; surface also marked by fine, concentric, sublamellose lines of growth which become more or less crowded toward the front.

The dimensions of a very perfect individual are: Length of pedicle valve from umbo to front margin, 23 millimeters; length of brachial valve, 17.75 millimeters; width of shell, 31 millimeters; thickness, 19 millimeters. The dimensions of a large pedicle valve, in part restored, are: Length, 32.5 millimeters; width, 52 millimeters; convexity, 11 millimeters.

Remarks.—Swallow's type specimens of this species were collected at the locality now known as Fern Glen. The smaller examples of the species resemble *S. marionensis,* but they are much more convex in both valves, with a much more elevated mesial fold and impressed sinus anteriorly. The shape of the cardinal area of the pedicle valve is also different, the ventral margin sloping laterally toward the cardinal extremities, while in *S. marionensis* the two margins of the areas are essentially parallel. The manner of growth of the shell of this species is accountable for the difference in the form of its cardinal area from that of *S. marionensis*. The length of the hinge line continues to increase throughout the entire period of growth of the shell, although as the shell approaches maturity the elongation is proportionally less rapid; at the same time the height of the area is continuously increasing, so that the mature shell possesses the broadly subtriangular cardinal area. Another feature of this species which can sometimes be detected is the presence of slight crenulations upon the hinge line. The larger individuals approach *S. imbrex*, of the Burlington limestone, but they are more coarsely ribbed and exhibit less bifurcation of the plications.

SPIRIFER GRIMESI Hall

Plate 13, figures 1-2

1858. *Spirifer grimesi* Hall, Geological Survey of Iowa, volume 1, part 2, page 604, plate 14, figures 1-5.

1895. *Spirifer grimesi* H. & C., Paleontology of New York, volume 8, part 2 plate 30, figures 8, 16-19.

Description.—Shell large, varying from longitudinally to transversely subelliptical in outline, the length greater or less than the width, hinge line shorter than the greatest width, cardinal extremities obtusely angular or somewhat rounded. Pedicle valve strongly convex; beak rather large, incurved; cardinal area of moderate width, nearly flat toward the hinge line, becoming more strongly concave toward the beak, its ventral margin sharply defined, sloping regularly on each side from the beak toward the cardinal extremities, the slope becoming much more abrupt as it approaches the extremities; mesial sinus rather broad and shallow, rounded or more or less angular in the bottom, originating at the beak, where it is quite sharply defined, losing its definition anteriorly; lateral slopes convex, becoming more or less flattened toward the cardinal extremities. Brachial valve about as strongly convex as the pedicle; the mesial fold broad, ill defined, becoming more strongly elevated and often somewhat angular toward the anterior margin; lateral slopes convex, sometimes becoming more or less flattened toward the cardinal extremities. Surface of each valve marked by eighty or more depressed rounded bifurcating plications, about twenty or twenty-five of which occupy the fold and sinus. The minute surface markings consist of very fine radiating striæ, about six or eight of which occupy each plication, and by still finer concentric striæ, giving to the surface of perfectly preserved shells a finely cancellated ornamentation. A few concentric lines of growth of greater or less strength are usually present toward the anterior margin of the shell.

The dimensions of a nearly complete example: Length, 56 millimeters; width, 73 millimeters; thickness, ± 40 millimeters; length of hinge line, ± 62 millimeters.

Remarks.—This is a rather common species in the Fern Glen fauna, but it usually occurs in a more or less fragmentary condition. The Fern Glen examples, however, are entirely similar in size and general characters with similarly preserved specimens of the species from the Burlington limestone where the species typically occurs.

SPIRIFER CHOUTEAUENSIS n. sp.

Plate 13, figure 11

Description.—Shell suborbicular in outline, the length and breadth nearly equal, the hinge line about two-thirds the greatest width of the shell, cardinal extremities rounded. Pedicle valve strongly convex, prominent on the umbo, the beak small, pointed and incurved over the small more or less ill defined concave cardinal area, the lateral slopes concave toward the cardinal line, convex antero-laterally; sinus of moderate depth, continuing to the beak, rounded in the bottom, bounded laterally by rounded plications and marked by from two to four faint, depressed, rounded plications which are formed by the bifurcation once or twice of the lateral bounding plications. Brachial valve less convex than the pedicle, the lateral slopes more or less concave toward the cardinal line, convex antero-laterally; mesial fold convex, becoming more prominent anteriorly, marked by from two to four plications which are formed by the bifurcation of the single initial one at the beak. The lateral slopes of both valves each marked by from ten to twelve simple rounded plications which are separated by rounded furrows of similar width.

The dimensions of a specimen of average size are: Length, 19 millimeters; width, 21 millimeters; thickness, 15 millimeters; length of hinge line, 15 millimeters.

Remarks.—This species closely resembles *S. suborbicularis* of the Burlington limestone except in size. It is in most respects a miniature form of that species, adult individuals not attaining a greater length than 25 millimeters, while *S. suborbicularis* grows to be two or three times as large, but the plications of this species are less numerous and those of the fold and sinus are less well defined. The larger species of the higher fauna is doubtless genetically derived from this Kinderhook species.

The species is of common occurrence in the Chouteau limestone and has frequently been identified as *S. peculiaris,* but it may be distinguished from that species by its longer hinge line, its lower and more sharply defined cardinal area on the pedicle valve, and by its more nearly approximate beaks. The types of the species are from the Chouteau limestone of central Missouri and are not illustrated here. The species is an unusual one in the Fern Glen fauna and the example here figured does not exhibit its characters with entire satisfaction.

SPIRIFER FERNGLENENSIS n. sp.

Plate 13, figures 9-10

Description.—Shell small, subglobular in form, hinge line shorter than the greatest width of the shell, cardinal extremities rounded. Pedicle valve strongly convex, most prominent near the center, the umbo rather small; beak small, incurved; cardinal area small and ill defined, the ventral margins rounding into the lateral surfaces of the valve; mesial sinus shallow, rather narrow, rounded in the bottom, originating at the point of the beak, not marked by plications; lateral slopes strongly convex; as they approach the lateral and anterior margins the curvature becomes more abrupt, being nearly vertical in the adult shells, each slope marked by about seven broad, flat, and more or less obscure, simple plications. Brachial valve less convex than the pedicle, most elevated near the center, the mesial fold simple, rounded and not strongly elevated, the lateral slopes convex, curving most abruptly to the cardinal margin, marked by plications similar to those of the opposite valve.

The dimensions of a nearly perfect pedicle valve are: Length, 12.5 millimeters; width, 13.5 millimeters; convexity, 5.5 millimeters.

Remarks.—This species resembles *S. chouteauensis,* but is smaller and much more rotund in outline, with the beak of the pedicle valve less prominent and the cardinal area less conspicuous. The dimensions given above are of an average sized individual; the largest example observed has a length of 15 millimeters. The pedicle valve is most commonly preserved; only a few distorted brachial valves have been met with.

SPIRIFER PLENUS Hall

1858. *Spirifer plenus* Hall, Geology of Iowa, volume 1, part 2, page 603, plate 13, figures 4*a-d*.

1895. *Spirifer plenus* H. & C., Paleontology of New York, volume 8, part 2, plate 37, figures 32-33.

Description.—Shell wider than long, but somewhat variable in proportions, large individuals becoming more or less subglobose in form; hinge line a little shorter than the greatest width of the shell and the cardinal extremities a little rounded. Pedicle valve very prominent in the umbonal region, the beak rather blunt and somewhat incurved; mesial sinus originating at the beak, rounded in the bottom, becoming broad and deep anteriorly and in large individuals being much produced in a lingual extension, not sharply defined laterally; lateral slopes of the valve usually convex throughout, but sometimes becoming a little concave toward the cardinal extremities; cardinal area concave, becoming strongly so in large individuals; internally the dental plates are strongly developed and extend well toward the front of the shell; they are conspicuously bilamellate and cleave readily along their median plane; posteriorly a transverse plate connects the dental lamellæ, its direction being nearly parallel with the cardinal area, but somewhat depressed below the surface of the area. Brachial valve about equally convex with the pedicle, most prominent at about its middle point; median fold rounded, becoming strongly elevated toward the front; lateral slopes convex throughout or becoming a little concave toward the cardinal extremities. Surface of the shell marked by rather broad, flattened, simple plications upon the lateral slopes, there being fifteen to twenty upon each side of the fold and sinus on each valve; these plications are progressively smaller toward the cardinal extremities, the last five or more becoming very obscure; the fold and sinus are non-plicate; surface of both valves also marked by concentric lines of growth which are more or less irregularly developed.

The dimensions of two individuals from the Burlington limestone are: Length, 67 millimeters and 50.5 millimeters; width, 81 millimeters and 73 millimeters; length of hinge line, 73 millimeters and 62 millimeters; thickness, 60 millimeters and 41 millimeters.

Remarks.—*Spirifer plenus* is typically a member of the Burlington limestone fauna, and the above description has been made from examples occurring in that formation. In the Fern Glen formation a single example has been observed which is merely a fragment of the umbonal region of the pedicle valve, showing both the internal and the external surfaces. Interiorly this fragment clearly shows the strong dental plates which are so characteristic of the species and which are so unlike the similar parts of any other associated *Spirifer.*

SPIRIFERINA MAGNICOSTATUS n. sp.

Plate 13, figures 12-15

Description.—Shell small, broader than long, with the greatest width along the hinge line, the cardinal extremities often produced into mucronate extensions. Pedicle valve most prominent on the umbo, somewhat compressed toward the cardinal extremities; beak rather small and incurved; cardinal area low, concave, the cardinal margin sharply defined; mesial sinus of moderate depth, rounded in the bottom, bounded laterally by a pair of strong, rounded ribs which originate at the beak and which are prominently elevated above the plications of the lateral slopes; each lateral slope marked by three or sometimes four clearly recognizable rounded plications beyond those which limit the mesial sinus; they decrease gradually in size toward the cardinal extremities, and in shells greatly extended along the hinge line one or more additional, exceedingly faint ones may sometimes be detected; the largest of these lateral plications is distinctly smaller than those bounding the mesial sinus; internally the umbonal portion of the pedicle valve is solidified, at least in mature individuals; the diductor muscular impression is strongly defined and is divided longitudinally by an angular ridge which becomes more septum-like toward the beak, and which in younger examples with less completely solidified beaks doubtless became a distinct mesial septum. Brachial valve less strongly convex than the pedicle, compressed toward the cardinal extremities; mesial fold but little elevated, rounded, with a faint mesial line which is scarcely a depressed furrow; the furrows bounding the mesial fold are somewhat more strongly impressed than the others upon the lateral slopes; the plications on the lateral slopes similar to those of the pedicle valve. Surface of both valves marked by fine, but strong and conspicuous, regular, concentric, sublamellose lines of growth which are distinctly arched toward the beak in passing over the plications of the shell. Punctate shell structure has not been observed.

The dimensions of a somewhat crushed individual, more than usually extended along the hinge line, are: Length, 7 millimeters; width along hinge line, 24 millimeters; thickness, approximately 6 millimeters.

Remarks.—This is a common species in the Fern Glen fauna, but no perfectly preserved examples have been observed. The pedicle valves are much the more common, only three brachial valves having been seen. In many specimens only the central portion of the shell, including the beak, is preserved, and in but few examples is the extension of the shell along the hinge line shown. In the internal solidification of the beak of the pedicle valve this species resembles *S. solidirostris,* but this is a smaller shell, more extended along the hinge line and with fewer plications; it also lacks the distinct mesial plication of the fold and sinus of that species, and the cardinal area is much smaller. The more distinctive characters of the species seem to be the strong bounding plications of the sinus of the pedicle valve, the small cardinal area, and the extended hinge line.

The shell to which Miller has given the name *Spirifera novamexicana* from Lake valley, New Mexico, is certainly congeneric with this species from the Fern Glen beds of the Mississippi valley and is a close ally, although the two species are probably distinct.

SPIRIFERINA SUBTEXTA White

Plate 13, figures 16-19

1862. *Spiriferina ? subtexta* White, Proceedings of the Boston Society of Natural History, volume 9, page 25.

1901. *Spiriferina subtexta* Weller, Transactions of the Academy of Science of Saint Louis, volume 11, page 199, plate 20, figures 5-6.

Description.—Shell of medium size, wider than long, the hinge line a little shorter than or perhaps sometimes equaling the greatest width of the shell, the cardinal extremities usually, perhaps always, a little rounded. Pedicle valve with a prominent beak which is rather sharply pointed and moderately incurved; cardinal area rather high, moderately concave, with a narrow delthyrium, not very sharply defined along the cardinal margin; mesial sinus originating at the beak, becoming prominent anteriorly and subangular in the bottom; lateral slopes convex, very slightly or not at all compressed toward the cardinal extremities, each marked by from seven to nine rounded plications, including those bounding the mesial sinus, which are successively smaller in passing toward the cardinal extremities; only one or two reach the beak, the others terminating along the cardinal margin. Surface of the shell marked by fine, regular, concentric, sublamellose lines of growth. Shell structure punctate.

The dimensions of a nearly perfect pedicle valve are: Width, 15.5 millimeters; length from beak to anterior margin, 10.5 millimeters; height of cardinal area, 3.7 millimeters.

Remarks.—This species is represented in the collection by incomplete examples only, the pedicle valves being the best preserved. In the original description of the species it is said to have "five or six prominent plications on each side of the mesial fold and sinus," but the Fern Glen examples possess from seven to nine plications upon each lateral slope, although about six are usually all which can be said to be prominent. The species is perhaps most closely allied to *S. solidirostris,* but it may be distinguished at once by the absence of the median plication of the fold and sinus. It may be distinguished from the associated *S. magni-*

costata by its larger size, its much larger cardinal area, and its proportionately smaller plications. The presence of a median septum in the shell has not been established.

CYRTINA BURLINGTONENSIS Rowley

Plate 13, figures 20-23

1893. *Cyrtina burlingtonensis* Rowley, American Geologist, volume 12, page 308, plate 14, figures 15-17.

Description.—Shell obliquely subpyramidal in form, the hinge line usually a little shorter than the greatest width of the shell, and the cardinal extremities rounded. Pedicle valve strongly convex, the beak acuminate and incurved over the cardinal area; cardinal area high, strongly arched posteriorly, its lateral margins not sharply defined, but rounding regularly into the lateral slopes of the shell; delthyrium narrow, closed by a rather strongly convex pseudo-deltidium which is pierced by a small foramen situated close up under the beak; surface of the valve marked by from three to five rounded plications upon each lateral slope; the two median plications are the larger and extend to the beak; the remaining ones grow successively smaller toward the cardinal extremities and become obsolete near the cardinal margin; between the two median plications is a rounded median sinus which originates at the beak. Brachial valve depressed convex, sometimes nearly flat, wider than long, marked by plications similar to those of the pedicle valve; the median plication is the broadest, although it is but slightly elevated above the adjacent lateral ones. In addition to the plications, the surface of each valve is marked by more or less irregular concentric lines of growth.

The dimensions of two nearly perfect specimens from the Chouteau limestone are: Width of shell, 13 millimeters and 9.8 millimeters; length of hinge line, 11.5 millimeters and 7.5 millimeters; length of pedicle valve from front to beak, 13.6 millimeters and 10 millimeters; height of area from hinge line to tip of beak, 5 millimeters and 4 millimeters; length of brachial valve, 9.5 millimeters and 7 millimeters.

Remarks.—This species was first described from the white cherts at Louisiana, Missouri, but it seems to occur most commonly in the Chouteau limestone of Pettis county, Missouri. In the Fern Glen fauna a single specimen, a somewhat crushed and distorted pedicle valve, has been observed, but it possesses all the essential specific characters of the Chouteau limestone examples. The species may be distinguishd from other members of the genus with which it might be confused by the rounded instead of angular cardinal margins.

SYRINGOTHYRIS SAMPSONI n. sp.

Plate 14, figure 4

Description.—Pedicle valve with an enormously elevated cardinal area whose height is about equal to its width along the hinge line; throughout the greater part of the area its surface is essentially flat, but it becomes a little concave toward the beak; the delthyrium is narrowly triangular, its width at the base being less than one-third its total height; beak pointed, rather small, a little curved; anterior and lateral slopes of the valve poorly preserved in the specimen examined, but a non-plicate median sinus is present which originates at the beak and is apparently rounded in the bottom, becoming profound anteriorly; the markings of the lateral slopes are not well preserved, but doubtless were similar to those of the opposite valve; the cardinal margins between the lateral slopes and the cardinal area are apparently sharply defined. Brachial valve depressed convex, with a median fold which is depressed convex toward the beak, but becomes elevated somewhat strongly toward the front; the lateral slopes marked by simple, rather broad, depressed convex plications, of which there are about fifteen on each side of the fold. Surface of the shell marked by minute papillæ arranged in concentric rows, about seven or eight occupying the space of 1 millimeter; the papillæ of successive rows are alternate in position, and extending anteriorly from each is a minute groove which terminates at about the line of the next succeeding row of papillæ; taken in the aggregate, these grooves give to the surface the appearance of being covered with minute shingles with a papilla at the lower extremity of each.

The approximate dimensions of the best example observed are: Length of hinge line, 74 millimeters; height of cardinal area, 57 millimeters; width of delthyrium at hinge line, 16 millimeters; length of brachial valve, 45 millimeters.

Remarks.—Aside from some fragments too imperfect to show the real characters, this species is represented in the collection by a single example, which is made the type. The specimen is badly crushed anteroposteriorly, but nearly the entire cardinal area is preserved with but slight distortion. The species may be distinguished from other members of the genus by its proportionately higher cardinal area, it being more nearly approached in this respect by *S. typa.* In the proportions of its area the species is most nearly like the European *S. cuspidatus,* but in its typical form the area of that species is convex, sometimes strongly so,[7] while in the Fern Glen species the area is concave toward the beak.

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[7] See Martin: Petrif. Derb., pls. 46-47, figs. 3, 4, 5.

ATHYRIS LAMELLOSA (*L'Eveille*)

Plate 14, figures 5-6

1835. *Spirifer lamellosus* L'Eveille, Memoires de la Société Géologique de France, volume 2, page 39, figures 21-23.
1858. *Athyris lamellosa* Davidson, British Fossil Brachiopoda, volume 2, page 79, plate 16, figure 1; plate 17, figure 6.
1875. *Athyris lamellosa* ? Meek, Paleontology of Ohio, volume 2, page 283, plate 14, figures 6*a-b*.
1887. *Athyris lamellosa* De Koninck, Faune du Calcaire Carbonifère de la Belgique, part 6, page 79, plate 21, figures 1-5.
1895. *Athyris lamellosa* H. & C., Paleontology of New York, volume 8, part 2, plate 46, figures 16-20.

Description.—Shell transversely subelliptical, the valves moderately and subequally convex, the hinge line short. Pedicle valve obscurely flattened along the median line in the posterior half of the shell, the flattening gradually changing into a slight, ill defined mesial sinus anteriorly, the anterior margin of this portion of the shell sometimes being bent toward the opposite valve and produced into a mesial lingual extension of moderate size; beak small, pointed, incurved, and in close contact with the umbo of the brachial valve. Brachial valve slightly flattened along the mesial line posteriorly, the flattening being gradually transformed into an obscure, flattened mesial fold anteriorly, which sometimes becomes rather prominent near the anterior margin. Surface of both valves marked by parallel, concentric, lamelliform expansions which are commonly in large part destroyed, only their bases being retained.

The dimensions of an average specimen from the Fern Glen fauna, exclusive of the lamelliform expansions, are: Length, 22 millimeters; width, 26.5 millimeters; thickness, 11 millimeters; on the same example the anteriormost lamelliform expansion is produced 11 millimeters and is still not complete.

Remarks.—Individuals of this species in the Fern Glen fauna do not usually grow to so great a size as do specimens of the same species in the superjacent Burlington limestone, but in all essential characters the shells seem to be identical with each other and also with European members of the species. The largest Fern Glen specimen observed, a somewhat crushed individual, has a width of 44 millimeters, which is fully as large as some of those in the Burlington limestone.

CLEIOTHYRIS ROYSSI (*L'Eveille*)

Plate 14, figures 1-3

1835. *Spirifer de royssii* L'Eveille, Memoires de la Société Géologique de France, volume 2, page 39, plate 2, figures 18-20.
1859. *Athyris royssii* Davidson, British Fossil Brachiopoda, volume 2, page 84, plate 18, figures 1-11.
1887. *Athyris royssii* De Koninck, Faune du Calcaire Carbonifère de la Belgique, part 6, page 85, plate 19, figures 19-28.

Description.—Shell lenticular, the length somewhat less than the width, the two valves subequally convex. Pedicle valve moderately convex, the greatest depth a little posterior to the middle, the surface sloping more abruptly to the cardinal margin; mesial portion of the valve slightly flattened anteriorly and sometimes depressed in a slight, ill defined sinus; the beak small, pointed, in close contact with the umbo of the brachial valve. Brachial valve equally convex or sometimes slightly more convex than the pedicle, the greatest depth near the center, the mesial portion slightly flattened to meet the flattened portion of the pedicle valve. Surface of both valves marked by fine, regular, concentric, lamellose lines of growth, which, when the surface characters are perfectly preserved, are produced into rows of close set concentric, imbricating fringes of elongate, flattened spines.

The dimensions of a nearly perfect individual are: Length, 18 millimeters; width, 21 millimeters; thickness, 9.5 millimeters.

Remarks.—The name *Athyris* or *Cleiothyris royssii* has not always been correctly applied in America. These Fern Glen specimens, however, seem to be certainly specifically identical with this European species as it has been interpreted by Davidson and De Koninck. As the shell usually occurs, the concentric fringes of fine spines have been destroyed, so that only concentric, sublamellose markings are preserved, although a few examples have been observed which preserve in part the fringes of spines. The species resembles *C. hirsuta* Hall, but it grows to a larger size and is proportionally broader. It differs from *C. sublamellosa* Hall in its more nearly equally convex valves, that species having the brachial valve much more convex than the pedicle, and also in its greater proportional width.

CLEIOTHYRIS INCRASSATA Hall

Plate 14, figures 8-10

1858. *Athyris incrassatus* Hall, Geology of Iowa, volume 1, part 2, page 600, plate 12, figure 6.
1895. *Athyris incrassata* H. & C., Paleontology of New York, volume 8, part 2, plate 46, figure 21; plate 83, figure 39.

Description.—Shell biconvex, transversely subelliptical in outline, the hinge line much shorter than the greatest width of the shell, the cardinal extremities rounded. Pedicle valve most prominent on the umbo, the surface curving abruptly to the cardinal margin and more gently to the lateral and antero-lateral margins; the median portion of the shell is depressed in a rounded, ill defined sinus which originates on or just in front of the umbo and becomes profound anteriorly; the curvature of the surface along the median line is strong, the anterior portion of the median sinus being directed at nearly a right angle to the plane of the valve; the beak rather small and pointed, incurved, in contact with the umbonal surface of the opposite valve. Brachial valve most prominent along the median line in the anterior half of the shell, where the rounded mesial fold is rather strongly elevated; lateral slopes convex, most abrupt toward the cardinal and antero-lateral regions of the shell. Surface of both valves, as usually preserved, marked by fine, more or less regular, imbricating lines of growth which are often somewhat wavy along their free margins. When perfectly preserved, these concentric lines were produced throughout as thin, flat spines lying in close apposition to the surface of the valve.

The dimensions of a somewhat imperfect individual are: Length, 40 millimeters; breadth, 56 millimeters; thickness, 26 millimeters.

Remarks.—As this species sometimes occurs in the somewhat shaly beds of the Fern Glen formation, the nature of its surface markings may be clearly determined, although in no cases have the spinose extensions of the concentric lamellæ been observed except in small patches. These markings are clearly those of the genus *Cleiothyris.* As the species occurs in the superjacent Osage limestones, the surface of the shell is uniformly more or less exfoliated, so that the fine surface details are destroyed.

In its general form and surface characters this shell closely resembles *Spirifer glabristria* Phillips, which is placed among the synonyms of *Athyris royssii* by Davidson, and it is altogether probable that the American and European specimens are members of a single species, although it is not so certain that the *glabristria* should be included under *Cleiothyris royssii.*

CLEIOTHYRIS PROUTI (*Swallow*)

Plate 14, figures 12-15

1860. *Spirigera proutii* Swallow, Transactions of the Academy of Science of Saint Louis, volume 1, page 649.

1894. *Athyris proutii* Keyes, Missouri Geological Survey, volume 5, page 91.

Description.—Shell transversely subelliptical in outline, with rounded cardinal extremities and a conspicuous mesial fold and sinus. Pedicle valve strongly convex, most prominent posterior to the middle, the surface curving strongly from the umbo to the margins, but most abruptly to the cardinal margins; mesial sinus large and deep, rounded in the bottom, defined on each side by a rounded ridge, in old shells produced in front into a lingual extension of greater or less length; beak rather prominent, incurved, in close contact with the umbo of the opposite valve, pierced by a circular foramen. Brachial valve strongly convex, with a rounded mesial fold which becomes very prominent anteriorly in old shells; lateral slopes of the valve more or less strongly convex, dependent upon the age of the individual. Surface of both valves marked by closely arranged, thin, concentric, imbricating lamellæ, which are produced very regularly into fine, flattened spines, the spines of successive concentric rows being arranged in radiating series so that the entire surface, even when the spines themselves are in large part destroyed, presents the appearance of being regularly and finely marked in a reticulate manner.

The dimensions of two examples are: Length, 17.5 millimeters and 16 millimeters; width, 22.5 millimeters and 21.5 millimeters; thickness, 15 millimeters and 11 millimeters.

Remarks.—This species was originally described from the Fern Glen formation of Saint Louis county, Missouri, and is highly characteristic of the formation wherever it occurs. The species is quite different from any other American athyroid shell, but should be compared with the European *Athyris squamigera* De Koninck, with which it is possibly specifically identical. In the present paper the species is referred to the genus *Cleiothyris* not because the internal characters of the brachidium have been observed, but because of the character of its surface markings, which most closely resemble those of *C. royssii;* the concentric fringes of spines in the two species, however, are quite different, the spines of *C. royssii* being narrower and not being arranged in regular radiating series, as is so conspicuously the case in *C. proutii.*

The shell from Lake Valley, New Mexico, which Miller has described as *Spirifera temeraria* is clearly a very close ally of *Cleiothyris prouti* and will probably prove to be specifically identical.

PTYCHOSPIRA SEXPLICATA (*W. & W.*)

Plate 14, figure 11

1862. *Retzia sexplicata* W. & W., Proceedings of the Boston Society of Natural History, volume 8, page 294.

1894. *Retzia plicata* S. A. M., Eighteenth Report of the Geological Survey of Indiana, page 316, plate 9, figures 24-31.

1895. *Ptychospira sexplicata* H. & C., Paleontology of New York, volume 8, part 2, plate 83, figure 28.

1900. *Retzia ? raricosta* Rowley, American Geologist, volume 25, page 266, plate 5, figures 34-37.

1904. *Ptychospira sexplicata* Greger, American Geologist, volume 33, page 15.

Description.—Shell subcircular in outline, usually a little wider than long, but sometimes longer than wide, the valves subequally convex; hinge line about one-third as long as the width of the shell, the cardinal extremities rounded. Pedicle valve most prominent on the umbo, the beak rather blunt, slightly incurved, pierced by a small, circular foramen; cardinal area small, slightly arched, the delthyrium occupying nearly half its breadth along the hinge line; delthyrium closed by a pair of deltidial plates which are frequently destroyed in the specimens; surface of the valve marked by from six to twelve strong, rounded plications which are separated by deep rounded grooves about equal in width to the plications themselves; the two median plications are the strongest, the lateral ones becoming successively smaller toward the cardinal extremities, the outermost ones sometimes being almost obsolete. Brachial valve more uniformly convex than the pedicle, its most prominent point being near the center; the surface marked by from seven to thirteen strong plications, corresponding with those of the opposite valve. Besides the strong plications, the surface of both valves is marked by more or less indistinct concentric lines of growth which sometimes become crowded and conspicuous toward the margin of fully grown shells.

The dimensions of two very perfect individuals from the Chouteau limestone of Pettis county, Missouri, are: Length, 9 millimeters and 10 millimeters; width, 10 millimeters and 11 millimeters; thickness, 6.5 millimeters and 5.5 millimeters.

Remarks.—This little shell is one of the less common members of the Fern Glen fauna and usually occurs in a more or less crushed and imperfect condition. The above description has been made from Chouteau limestone specimens from Pettis county, Missouri, where the species occurs in a very perfect condition. The variation of the species consists chiefly in the number of plications upon the shell, those with the larger number being proportionally broader than the others, and in the convexity of the valves. *Retzia plicata,* described by Miller as having from ten to twelve plications, is not specifically different from White and Whitfield's shell with "only about six plications." In the Chouteau limestone at Sedalia, Missouri, where Miller's type specimens were collected, examples occur showing the whole range of variation of the species as regards the number of plications. The most usual number of plications seems to be eight on the pedicle valve and nine on the brachial valve, those adjacent to the cardinal line on each valve being rather faint. The convexity of the valves varies considerably, the broader individuals often being much thinner than the narrow ones, as is shown in the dimensions of the two individuals given above.

RETZIA CIRCULARIS S. A. M.?

Plate 12, figure 23

1894. *Retzia circularis* S. A. M., Eighteenth Report of the Geological Survey of Indiana, page 316, plate 9, figures 32-34.

Description.—Shell small, subovate in outline, the valves subequally convex, the length and breadth subequal, the greatest breadth at or near the middle, the postero-lateral margins meeting at the beak in nearly a right angle. Pedicle valve with a small, pointed beak, the greatest convexity posterior to the middle, the surface rounding to the margin in all directions, but most abruptly toward the cardinal line; along its median line the valve is slightly flattened or sometimes very slightly depressed to form an obscure mesial sinus, the apparent sinus being mostly due to the partial suppression of the median plication; the brachial valve with its greatest convexity posterior to the middle, from which point the surface slopes to the margin with a convex curve in all directions, most abruptly posteriorly and postero-laterally; surface of each valve marked by from twelve to fifteen simple, subangular plications which are about equal in width with the intervening furrows; no concentric markings of the shell are visible.

The dimensions of a nearly complete individual are: Length, 5.2 millimeters; breadth, 5 millimeters; thickness, 2.5 millimeters.

Remarks.—This species is one of the less common members of the Fern Glen fauna. It seems to agree in general form with the specimens of *Retzia circularis* from the Chouteau limestone of central Missouri, from where that species was originally described, but it differs from authentic examples in the partial suppression of the median plication of the pedicle valve, and in the somewhat finer plications of the Fern Glen examples. The internal structures of the species are unknown, but it is not improbable that it should be referred to the genus *Ptychospira* along with *P. sexplicata.* The shell also resembles *Rhynchonella tuta* S. A. M., from Lake Valley, New Mexico, but judging from the figures and description alone, it seems to differ from that species in a manner similar to its differences from the authentic examples of *Retzia circularis.*

DIELASMA FERNGLENENSIS n. sp.

Plate 14, figure 7

Description.—Shell large, subovate in outline, narrower posteriorly, the greatest width anterior to the middle of the shell; shell structure finely punctate. Pedicle valve badly crushed in the type specimen, but apparently moderately convex, with a prominent arched beak perforated by a large foramen. Brachial valve probably about as convex as the pedicle. Both valves marked by several moderately strong lines of growth toward the margin.

The dimensions of the type specimen are: Length, 55 millimeters; width, 43 millimeters; thickness, probably from 20 to 25 millimeters originally, in the undistorted specimen.

Remarks.—This species is represented in the collections by a few fragmentary or badly crushed and distorted specimens only, so that its characters can not be entirely made out. It is characterized, however, by its large size, and differs from other members of the genus of similar size in the Mississippian faunas in its more broadly ovate form and the moderate convexity of the valves.

MOLLUSCA

PELECYPODA

AVICULOPECTEN FERNGLENENSIS n. sp.

Plate 15, figure 19

Description.—Shell but slightly oblique, higher than wide, the greatest width near the middle. Body of the shell, exclusive of the auriculations, ovate in outline, rather strongly convex in the right valve, which is the only one known. Posterior auriculation depressed convex, sharply defined from the body of the shell, the postero-cardinal angle acute, the posterior margin nearly straight, separated from the posterior margin of the body of the shell by a subangular sinus of moderate depth. Anterior auriculation not preserved, but apparently more sharply separated from the body of the shell than the posterior one. Surface of the shell marked by narrow, sharply angular, radiating costæ, which are narrower than the intervening furrows and which are more or less alternating in size; the costæ grow regularly smaller in size toward the posterior cardinal extremity and are present upon the posterior auriculation; their characters anteriorly are not known, but they probably also cover the anterior auriculation. Besides the radiating costæ, the surface is covered with very fine raised concentric lines, and at intervals by strong, concentric lines of growth which are produced into lamellose extensions, especially toward the cardinal extremities.

The dimensions of the type specimen, a right valve, are: Height, 34.5 millimeters; width, approximately 27 millimeters; length of hinge line on posterior side of beak, 12 millimeters; convexity, approximately 6 millimeters.

Remarks.—This species is based primarily upon a single incomplete right valve, which does not exhibit all the characters as well as might be desired, and the dimensions given above, in some cases at least, are liable to be in error because of the distortion of the specimen. A fragment of another example, which possibly belongs to the same species, represents a much larger shell with much more strongly developed concentric growth lamellæ. The species is characterized by its slight obliquity and by the peculiar character of the surface markings.

CONOCARDIUM sp. undet.

A few fragments of a shell which seems to be a member of the genus *Conocardium* have been observed in the Fern Glen fauna, but none of them are perfect enough to allow the species to be identified or described if it is an undescribed form, as is entirely probable.

GASTROPODA

PLATYCERAS PARALIUS W. & W.

Plate 15, figures 17-18

1862. *Platyceras paralium* W. & W., Proceedings of the Boston Society of Natural History, volume 8, page 302.

1894. *Capulus paralius* Keyes, Missouri Geological Survey, volume 5, page 174, plate 2, figures 1*a-b*.

Description.—Shell of medium size, more or less carinate, usually closely coiled at the apex through about one somewhat oblique volution, beyond which the body volution becomes free, the sides of the outer volution spreading rather rapidly. Aperture subcircular to subelliptical in outline, but usually subcircular in undistorted shells, the margin more or less denticulate with rounded points and sinuses. Surface of the shell marked by more or less distinct, but sometimes obscure, flattened or depressed convex, longitudinal ribs, which are projections of the marginal denticulations and which become more obscure toward the apex of the shell; surface also marked by fine transverse lines, with an occasional stronger line of growth whose direction is parallel with the irregular margin of the shell.

The dimensions of two individuals are: Extreme length of the shell, 34 millimeters and 27.5 millimeters; length of aperture, 22 millimeters and 19 millimeters; width of aperture, 25 millimeters and 21 millimeters; greatest height of shell, 16 millimeters and 15 millimeters.

Remarks.—This is a rather common species in the Fern Glen fauna, and like all members of the genus it exhibits a considerable range of variation because of the sedentary habits of growth. One of the most noticeable variations is in the curvature of the apex of the shell. The normal condition of the apex is as has been described above, but examples are occasionally met with in which the apex is not coiled at all, the shell being a more or less oblique or curved conical shell, such a form probably being assumed from the effect of gravity during the growth of the shell, due to the position of the shell during life.

CEPHALOPODA

ORTHOCERAS sp. undet.

Fragments of a species of Orthoceras are sometimes met with in the Fern Glen fauna. In their present condition they rarely retain more than two or three chambers and are all crushed so as to have a subelliptical outline, although they were probably originally circular in cross-section. No characters which may be used for specific determination are preserved.

CYRTOCERAS ? sp. undet.

A single fragment of a curved cephalopod shell has come under observation. Only three chambers are preserved, and these imperfectly. The shell is subelliptical in cross-section, the larger diameter being transverse to the plane of curvature; the siphuncle is situated excentrically toward the ventral side.

ARTHROPODA

TRILOBITA

PROËTUS FERNGLENENSIS n. sp.

Plate 15, figures 20-22

Description.—Entire body subovate in outline, strongly convex, the greatest width about five-eighths of the total length. Cephalon subcrescentic, the genal angles produced into conspicuous spines, the marginal border broadly rounded, marked by about four narrow costæ subparallel with the outer margin; glabella strongly convex, well defined by the dorsal furrows, slightly protuberant in front, the lateral outlines a little convex and gently converging in front of the eyes, the anterior margin broadly rounded; glabellar furrows and lobes not well preserved in the type specimen, but a large, strongly convex basal lobe is present, and apparently two lateral furrows on each side which are in close proximity to each other and to the furrow bounding the basal lobe; cheeks sloping steeply from the eyes to the marginal furrow, where they are deflected nearly horizontally into the marginal border; eyes not preserved in the specimen. Thorax with ten segments, the axis more than one-third the width of the body, well defined and strongly convex; proximal portion of the pleura nearly horizontal, the distal half bent abruptly downward at an angle of about 120 degrees. Pygidium rather short, subsemicircular in outline, but not well preserved in the type specimen.

The dimensions of the type specimen are: Total length, 55 millimeters; length of cephalon, approximately 19 millimeters; width of cephalon, 35 millimeters; convexity of cephalon, 13.5 millimeters; convexity of thorax, 12 millimeters; length of pygidium, 9 millimeters.

Remarks.—The type specimen of this species is a somewhat weathered, complete individual, upon which some of the characters are obscure. A few imperfect pygidia have been observed which probably belong to the same species; also an occasional broken genal spine. The species is perhaps more nearly like *P. missouriensis* than any other, but that species is proportionately longer, with a glabella which is somewhat broader and subtruncate in front. The costæ parallel with the margin in the marginal border of the head seem to be a characteristic feature of the species.

CORRELATION

IN GENERAL

In the correlation of the Fern Glen fauna it is necessary to compare it with the faunas of the Chouteau and Burlington limestones, with that of the Saint Joe marble of Arkansas, the New Providence shale of Indiana and Kentucky, and the Lake Valley beds of New Mexico.

RELATION OF THE FERN GLEN TO THE CHOUTEAU AND BURLINGTON

The relations of the Chouteau limestone as a formation have been much misunderstood. The almost universal custom of considering it as the upper member of a threefold classification of all of the Kinderhook beds of the Mississippi Valley region is due to an entirely mistaken interpretation. In the region of its typical development in central Missouri, the Chouteau represents the entire Kinderhook interval and is probably contemporaneous in part with the Louisiana limestone of northeastern Missouri, which was being deposited in an entirely separate basin. The so-called Chouteau of northeastern Missouri and Iowa is not the typical Chouteau, and is to be correlated with the highest beds of the Chouteau in central Missouri only. In following the Chouteau limestone into southwestern Missouri it is found to occur with its typical lithologic and faunal characters, but much reduced in thickness, near the base of the Kinderhook, and not at the summit, as it is usually represented in geologic sections of that region.[8] In the Mississippi River section the same limestone, similar and sometimes identical in its lithological characters with the formation at its most typical exposures at Chouteau springs, Missouri, occurs at many localities in Missouri and Illinois. A large fauna has been collected from the formation in Calhoun county, Illinois, which is identical in every respect with the fauna at Chouteau springs. In the sections where the Fern Glen has its typical development the limestone immediately beneath the red beds is the Chouteau, although in none of these localities has it afforded a characteristic fauna or in fact any fauna at all representative.

A discussion of neither the entire fauna of the Chouteau limestone nor any considerable part of it has ever been brought together in one place, and many species in the fauna are as yet undescribed. Furthermore, all of the species of the Chouteau of central Missouri should not be considered as constituting a unit fauna, but the zonal distribution of the species should be investigated. Under these circumstances, therefore, it is impracticable to make a detailed comparison of the Fern Glen with the Chouteau fauna. However, the most characteristic and typical Chouteau species, such as *Spirifer peculiaris, Pugnax missouriensis, Reticularia cooperensis, Productella cooperensis, Promacrus nasutus, Triboloceras digonum,* and *Schizoblastus roemeri,* do not occur in the Fern Glen fauna, nor do they have any close relatives. Among the previously described brachiopods in the Fern Glen, excluding *Spirifer vernonensis* and *Cliothyris prouti,* which were originally described from this formation, all except one, *Cliothyris incrassata,* do occur in the uppermost, non-typical beds of the Chouteau of central Missouri, in the Pierson limestone, which is the equivalent of these beds in southwestern Missouri, and in bed number 7 of the Burlington, Iowa, section, which is immediately subjacent to the Burlington limestone. Several of the more conspicuous brachiopods of the fauna also pass over into the Burlington limestone, and some of these are among the most abundant members of the Lower Burlington fauna. Such species are *Leptæna rhomboidalis, Schizophoria swallovi, Rhipidomella michelinia, Chonetes illinoisensis, Spirifer grimesi, Athyris lamellosa,* and *Cliothyris incrassata.* Other members of the Fern Glen fauna, especially among the crinoids, have close relatives among the Lower Burlington species, and in a few cases are, or seem to be, identical as in the case of *Synbathocrinus dentatus, Vasocrinus* cf. *macropleurus, Metichthyocrinus* cf. *burlingtonensis,* and *Cœlocrinus* cf. *ventricosus.*

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[8] This Upper Kinderhook formation in Green county, Missouri, and elsewhere in the southwestern portion of the state, has been called the Pierson limestone by the writer in Journal of Geology, vol. 9, p. 144.

From the evidence presented, therefore, it is clear that while the Fern Glen may still be included in the Kinderhook as a contemporaneous formation with the highest, non-typical portion of the Chouteau limestone, it represents the closing stages of the Kinderhook, and in its fauna is foreshadowed the beginning of the succeeding life of the Lower Burlington.

THE SAINT JOE MARBLE

The Saint Joe marble is a pink or reddish limestone with a wide distribution in northern Arkansas, lying immediately beneath the Boone chert formation. The color of the Saint Joe is essentially identical with that of the Fern Glen formation in its typical condition, and the more calcareous parts of the Fern Glen are indistinguishable in hand specimens from the Saint Joe. The most complete records of the fauna of the Saint Joe marble have been given by Williams.[9] The identifications in these lists are in some cases now known to be incorrect, but they give a good idea of the composition of the fauna. Faunal lists from eight localities are given which are combined in a single list given below on the left, the number following each name indicating the number of localities from which the species has been recorded in Arkansas. The list on the right, here given, indicates the Fern Glen species which are identical with or represent the Arkansas forms. In a number of cases the same species has been recorded in Arkansas under two or more names; these are indicated in the table by the use of brackets.

In the table (page 324) the Fern Glen species mentioned are in every case specifically identical with the corresponding Saint Joe marble forms, except *Camarotœchia persinuata* and *Spiriferina subtexta,* and these two also are possibly identical. With one exception only, *Pugnax acuminatus,* every one of the Saint Joe species not represented in the Fern Glen are either incompletely or questionably identified. The species in the Saint Joe marble which occur in three or more localities are as follows:

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[9] Annual Report of the Arkansas Geological Survey, 1892, vol. 5, Lead and Zinc, pp. 331-334.

Rhipidomella michelinia, Productus sampsoni, Spirifer grimesi, Spirifer chouteauensis, Spirifer vernonensis, Athyris lamellosa, and *Cliothyris prouti.* This group of species, with the possible exception of *Spirifer chouteauensis,* includes by far the most characteristic brachiopods of the Fern Glen fauna, and the lists as a whole show beyond question the close relationship of the brachiopod elements in the two faunas.

Saint Joe marble fauna.	Fern Glen representatives.
Zaphrentis sp. 1.	
cf. *Zaphrentis tenella* Mill. 2.	
cf. *Scaphiocrinus missouriensis* Sh. 1.	
Leptæna rhomboidalis Wilck. 2.	*Leptæna rhomboidalis* Wilck.
{ *Schizophoria resupinata* Mart. *Schizophoria swallovi* Hall } 2.	*Schizophoria swallovi* Hall.
{ *Rhipidomella michelinia* Lev. *Rhipidomella thiemei* White *Rhipidomella vanuxemi* Hall } 6.	*Rhipidomella michelinia* Lev.
cf. *Chonetes ornatus* Shum. 1.	*Chonetes logani* N. & P.
Productella hallana Walc. 3.	*Productus sampsoni* n. sp.
Rhynchonella cooperensis Shum. 2.	*Camarotœchia persinuata* (Winch.).
Pugnax acuminatus Mart. 1.	
{ *Spirifer grimesi* Hall *Spirifer striatiformis* Meek } 4.	*Spirifer grimesi* Hall.
{ *Spirifer kinderhookensis* *Spirifer ovalis* Phil. } 4.	*Spirifer chouteauensis* n. sp.
Spirifer marionensis Shum. 3.	*Spirifer vernonensis* Swall.
Spirifer cf. *mesocostalis* Hall 1.	
Spiriferina octoplicata Sow. 1.	*Spiriferina subtexta* White.
{ *Athyris lamellosa* Lev. *Athyris hannibalensis* Swall. } 4.	*Athyris lamellosa* Lev.
Athyris prouti Swall. 3.	*Cliothyris prouti* (Swall.).
Athyris sp. 1.	
Cliothyris roissyi Lev. 1.	*Cliothyris roissyi* Lev.
Ptychospira sexplicata W. & W. 1.	*Ptychospira sexplicata* W. & W.
cf. *Dielasma burlingtonensis* White 1.	
{ *Capulus equilaterus* Hall *Capulus* sp. } 2.	*Platyceras paralius* W. & W.

In the non-brachiopod portion of the Fern Glen fauna there is no form more characteristic than the bases of the bryozoan genus *Evactinopora,* and although the presence of this genus was not recorded by Williams, it has been noticed in abundance by Ulrich.[10] The coral and crinoidal elements in the Saint Joe fauna are essentially unknown, but forms similar to those in the Fern Glen may be looked for.

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[10] U. S. Geological Survey, Professional Paper no. 24, p. 101.

The exact correlation of the Fern Glen with some part of the Saint Joe formation as it was interpreted by the members of the late Geological Survey of Arkansas may be assumed to be established. Unpublished data gathered by Dr E. O. Ulrich, however, suggest that a lower member, perhaps separated by a slight unconformity from the typical Saint Joe marble, was not sufficiently differentiated by the members of the Arkansas Survey. These lower beds are commonly fossiliferous, while good fossils are comparatively rare in the Saint Joe proper, and it is from these lower beds that most, if not all, of the material recorded by Williams was probably obtained. The exact correlation of the Fern Glen beds, therefore, will probably prove to be with these beds which are immediately subjacent to the typical Saint Joe marble, but which have been commonly united with that formation as a single formation unit.

THE NEW PROVIDENCE SHALE

The name New Providence shale was first applied many years ago to the basal portion of the so-called Knobstone group in southern Indiana by Borden,[11] and has been revived more recently by Newsom.[12] The formation includes from 50 to 120 feet of shales which immediately overlie the Rockford goniatite limestone, which carries a fauna with strong Chouteau affinities. The fauna of the New Providence shales in Indiana has been made known in an inadequate manner, the list furnished by Newsom[13] being incomplete and having some of the identifications probably incorrect.

The same formation extends into Kentucky, and a locality at Button Mould knob, south of Louisville, has been mentioned not infrequently by the older collectors of fossils from that region. A small collection of material from this locality has been available for study by the writer, which shows the fauna to be rich in small corals, among which are several species of *Cyathaxonia,* including *C. cynodon* E. & H., which was apparently originally described from this or a neighboring locality. This genus is one of the most common in the Fern Glen fauna, and although the species in the two localities seem to be different, they are somewhat closely allied. Among the other corals, the species described in the present paper as *Amplexus rugosus* is represented in the Button Mould Knob fauna by perfectly typical examples, and *Monilopora crassa* is also common in the Kentucky locality. Several species of *Zaphrentis* which are not identical with, but are allied to, those of the Fern Glen fauna are present in the fauna. Aside from the corals, only a single species of brachiopod is contained in the collection, *Rhipidomella oweni* H. & C., which is a close ally and is perhaps not distinct from *R. michelinia*, the most abundant brachiopod in the Fern Glen fauna. The only blastoid recognized in the Fern Glen fauna is *Pentremites decussatus*, a species which was originally described from Button Mould knob, and an examination of the type specimen in the collection of Mr Frank Springer has shown the identification of the Fern Glen specimens to be correct.

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[11] Fifth Annual Report of the Geological Survey of Indiana, p. 161.
[12] Twenty-sixth Annual Report of the Geological Survey of Indiana, p. 261.
[13] Loc. cit., p. 278.

Although our knowledge of this basal Knobstone fauna is incomplete, the evidence available seems to indicate that a reasonably close correlation between it and the Fern Glen fauna can be made.

THE LAKE VALLEY BEDS[14]

A highly interesting Lower Mississippian fauna has been described by Miller[15] and by Springer[16] from Lake Valley, New Mexico. The list of species given by Springer is much more complete than that of Miller, but both lists need revision, in the light of the more recent investigation of the Mississippian faunas of the Mississippi valley. Any comparison of the fauna with that of the Fern Glen beds is entirely inadequate, in the absence of actual collections for study, but some suggestive observations may be made from the published lists alone.

The crinoids of the fauna, which constitute a very considerable element, point strongly to its Lower Burlington age. Springer says:

> "Every one of the species named belongs to the Lower Burlington (leaving out *A. copei*, which was described from Lake valley), and the new species are of the same types. Not a single species has been discovered that is peculiar to the Upper Burlington or any other group of the Subcarboniferous."

This same statement would be perfectly applicable to the crinoid fauna of the Fern Glen formation, as all of the previously known species occur in the Lower Burlington, and the new species are members of genera which are present in the same fauna and are mostly more or less closely allied to previously known species of that horizon.

Among the brachiopods in the fauna, such species as *Athyris lamellosa, Schizophoria swallovi, Leptæna rhomboidalis, Rhipidomella michelinia,*

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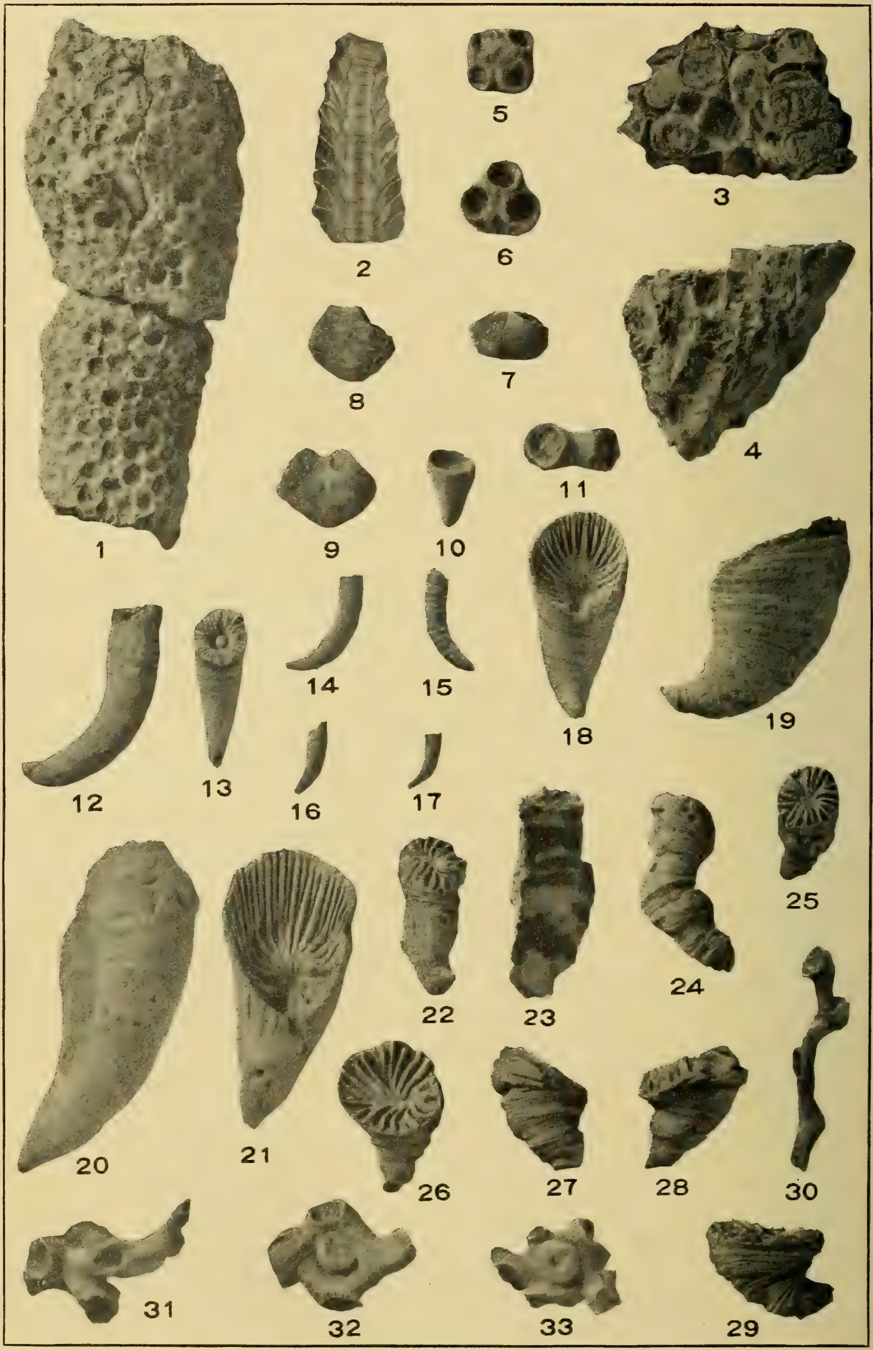
[14] Since this paper was written a collection of Lake Valley fossils has come into the hands of the writer through the generosity of Mr Frank Springer. Examination of this collection has confirmed and very much strengthened the supposed similarity of the fauna with that of the Fern Glen formation.

[15] Journal of the Cincinnati Society of Natural History, vol. 4, pp. 306-315, pl. 7.

[16] American Journal of Science (3), vol. 27, pp. 97-103.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etcetera, are abundant in the Fern Glen. The species which is described by Miller as *Spirifera temeraria* is clearly identical with *Cliothyris prouti,* which is one of the most characteristic species in the Fern Glen fauna and which does not occur in the superjacent Burlington at all.

Although a really critical comparison of the Lake Valley and Fern Glen faunas must await an opportunity to study the Lake Valley collections, yet the comparison which is possible from the literature alone suggests a rather close correlation of the two.

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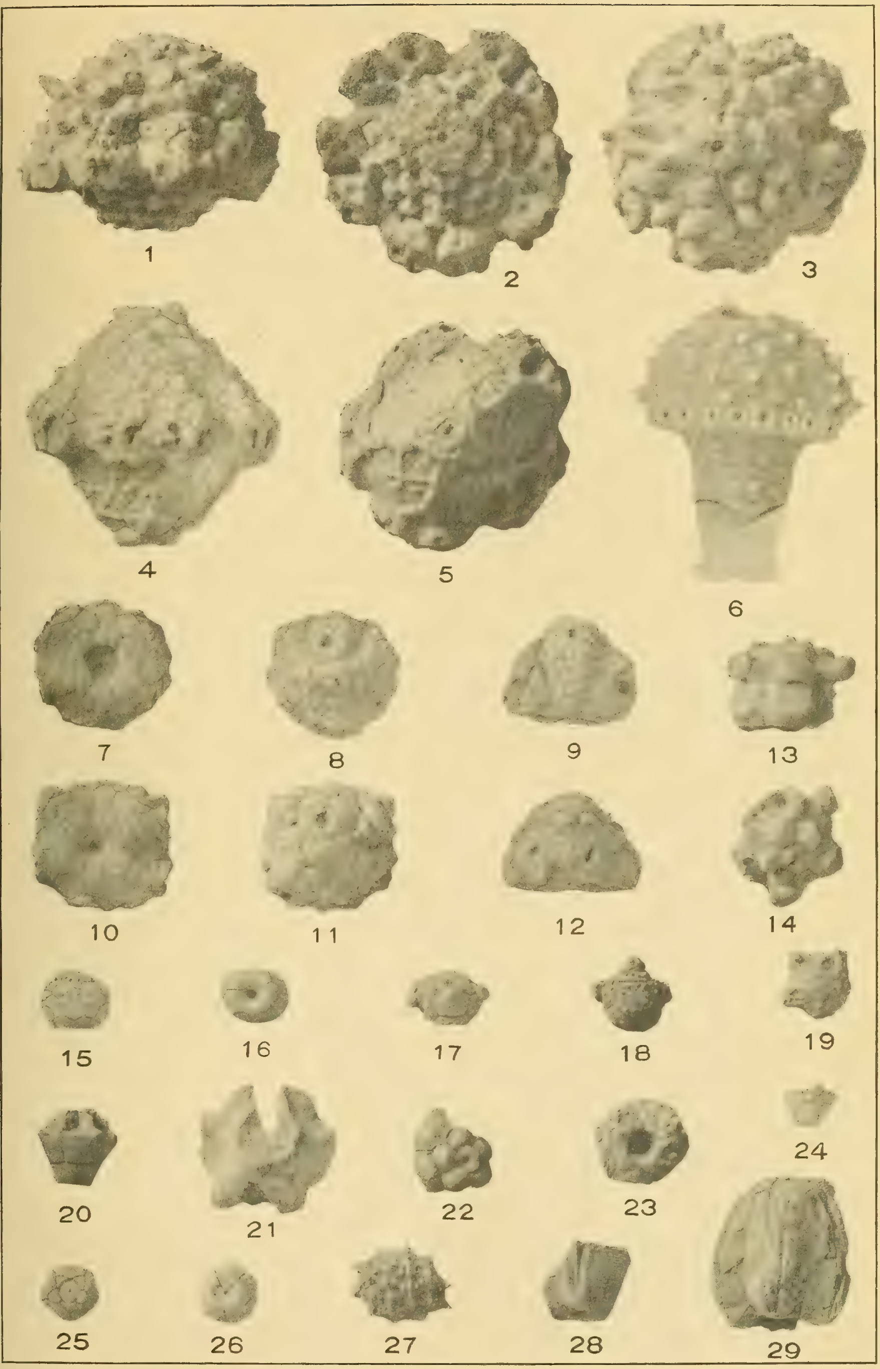

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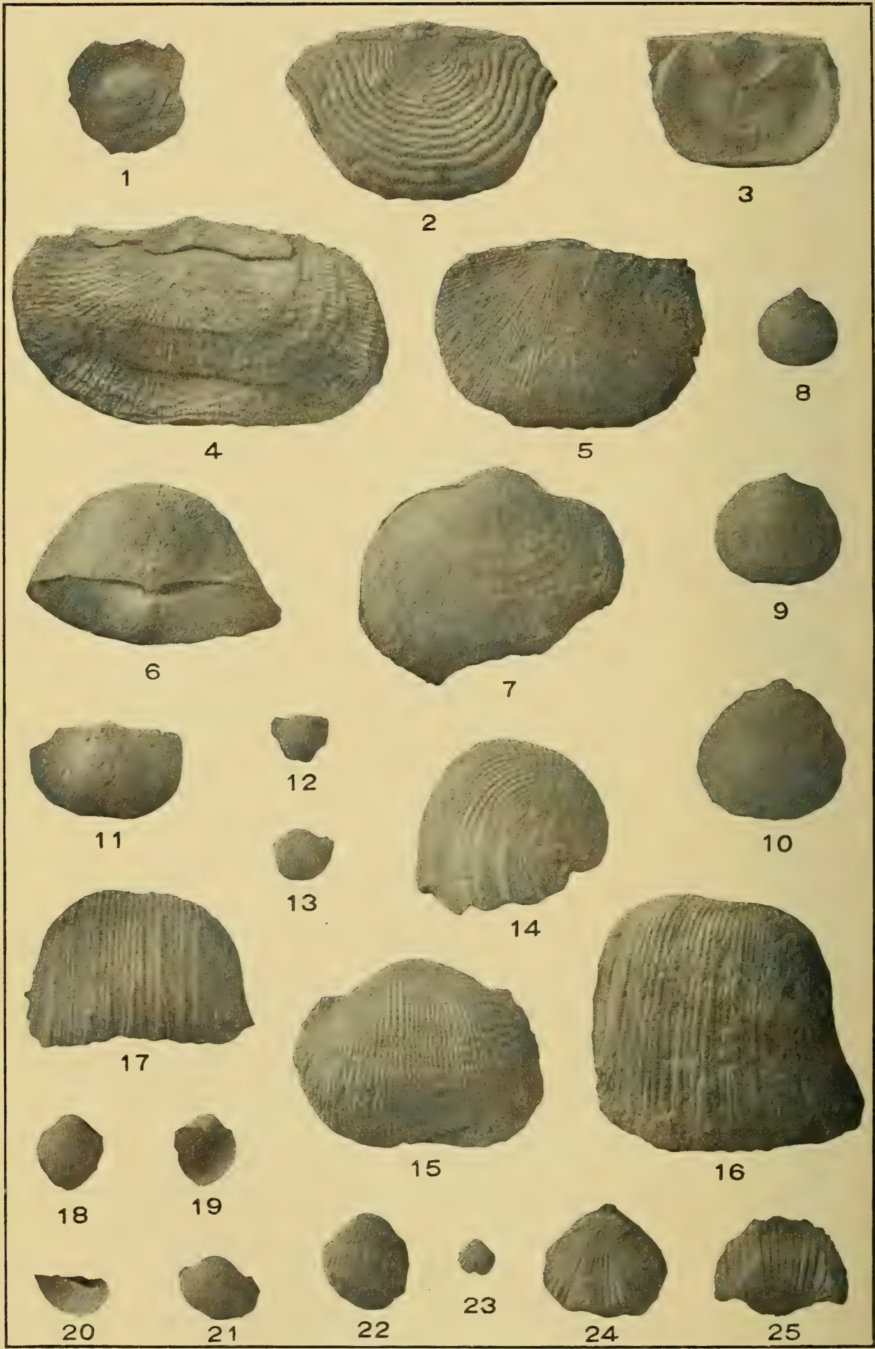
FERN GLEN FAUNA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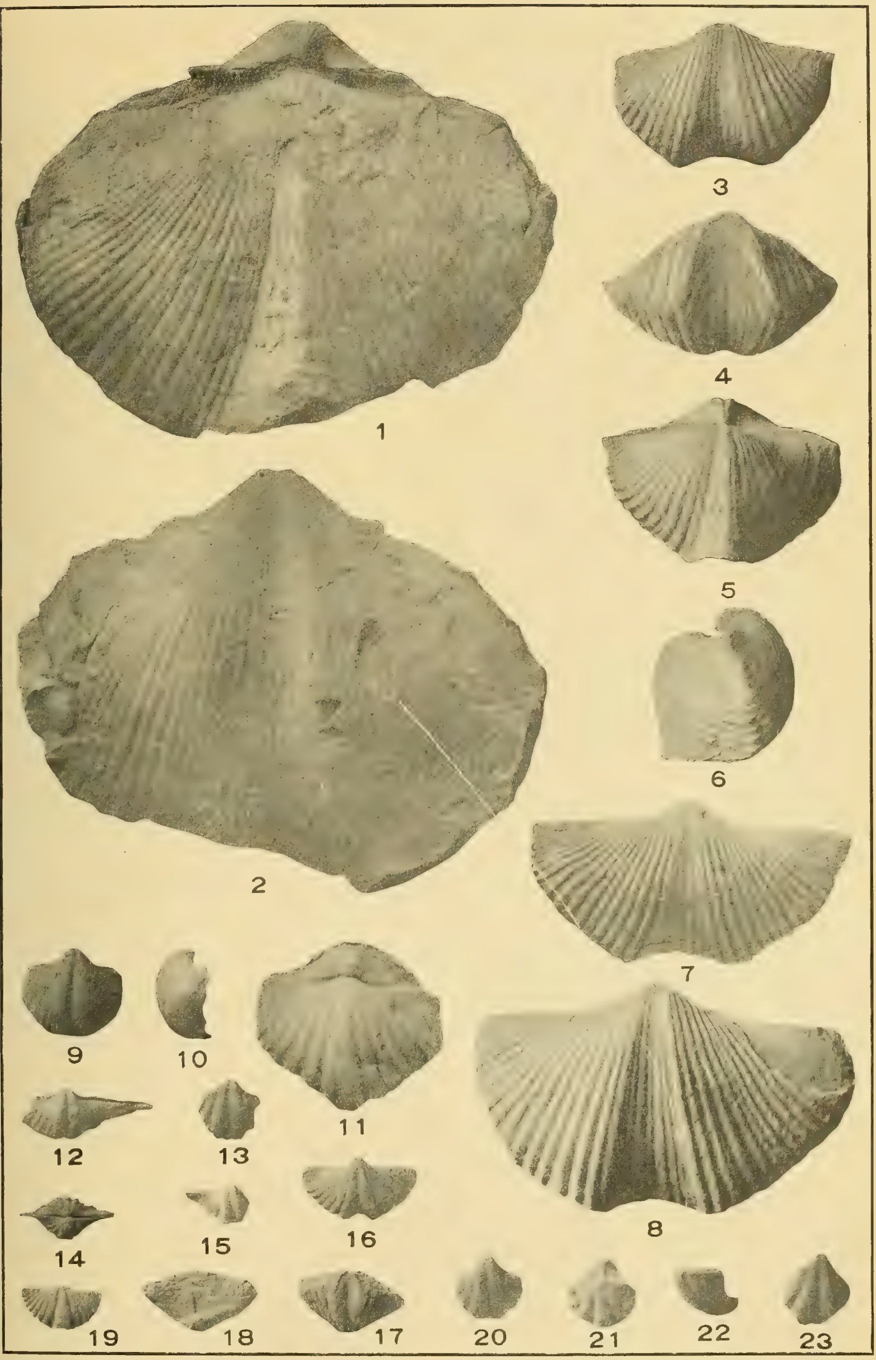
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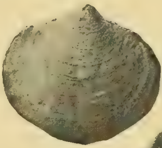
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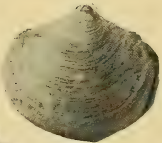
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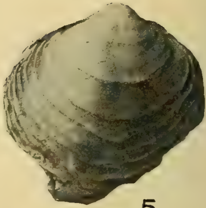
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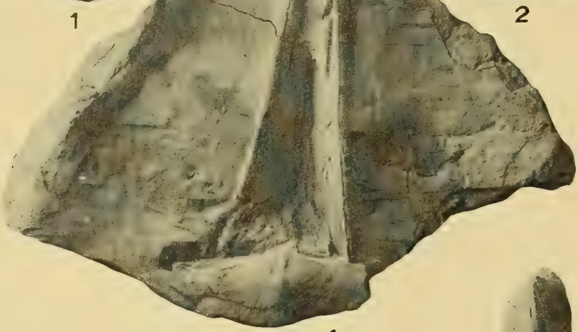
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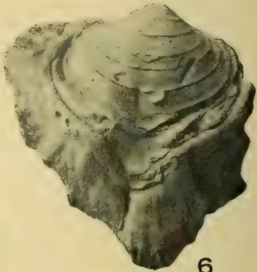
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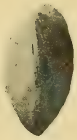
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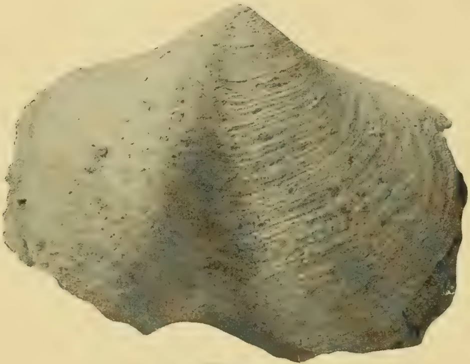
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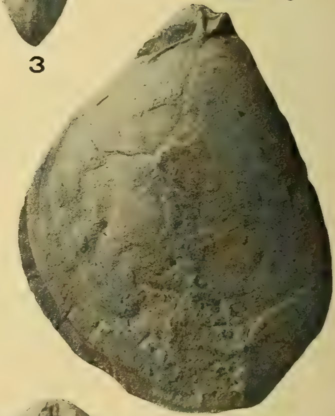
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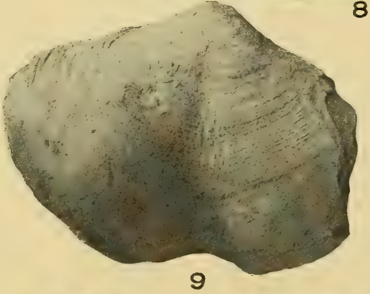
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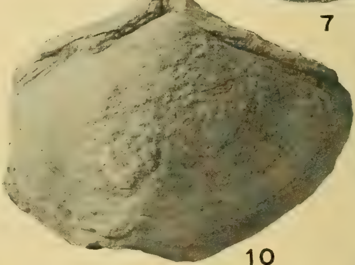
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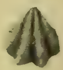
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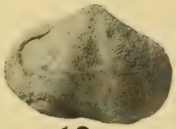
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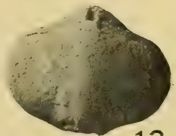
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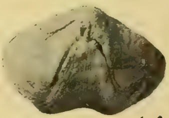
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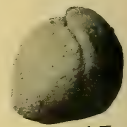
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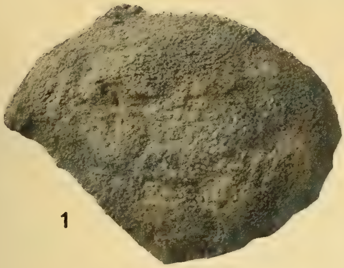
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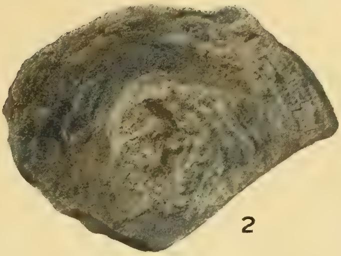
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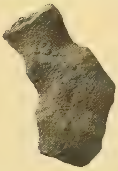
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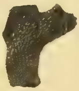
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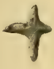
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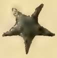
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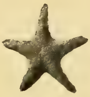
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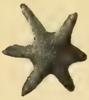
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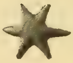
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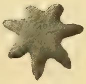
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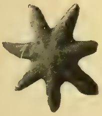
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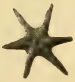
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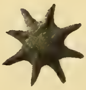
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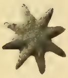
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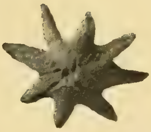
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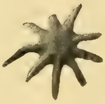
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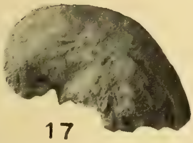
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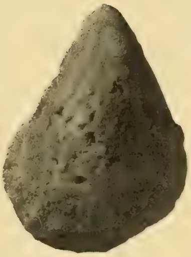
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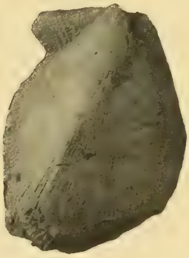
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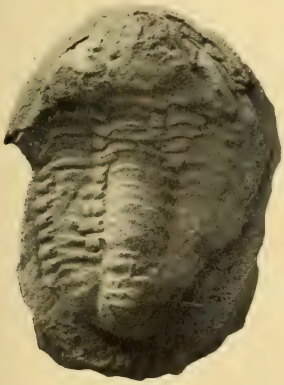
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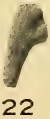
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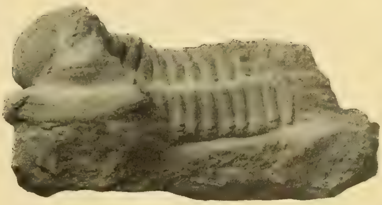
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FERN GLEN FAUNA

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 20, PP. 333-340 SEPTEMBER 15, 1909

SHORTAGE OF COAL IN THE NORTHERN APPALACHIAN COAL FIELD[1]

(*Presented before the Society December 31, 1908*)

BY I. C. WHITE

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THE BARREN AREA

It was formerly supposed that the several coal formations of the Appalachian region would hold coal of commercial value over the entire area of that great field. Your speaker pointed out, many years ago, that this was a grave mistake, so far as the Monongahela and Pottsville series are concerned, and, later, that the Allegheny and Kanawha coals also share the same fate when they pass under water level toward the center of the Appalachian basin; that, instead of a continuous sheet of *productive* Coal Measures underlying this entire field, there is a great *barren* zone which in the Allegheny series begins a few miles north from Pittsburg, and, embracing most of Allegheny county, a large portion of Westmoreland, practically all of Washington, Greene, and western Fayette, as well as southern Beaver, passes southwestward entirely across West Virginia and southeastern Ohio, thus reducing enormously the productive area of the Allegheny series and its usually estimated coal resources.

The celebrated Pittsburg coal holds its place in the series, however, until we reach Doddridge county, western Wetzel, and eastern Tyler, in West Virginia, when it, too, disappears, except in scattered patches along its eastern crop through Lewis, Braxton, Gilmer, Roane, Kanawha, and

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[1] Manuscript received by the Secretary of the Society August 28, 1909.
This paper was also presented before the American Mining Congress in December, 1908, under the title "The Barren Zone of the Northern Appalachian Coal Field."

Putnam counties, as we may see by inspection of the coal map of the West Virginia Geological Survey. The same thing happens to this coal in southeastern Ohio, so that it is practically absent from Monroe, Washington, eastern Athens, much of Meigs, and Gallia.

These facts have been brought to light principally by the oil-well drillers in the search for petroleum and natural gas. The great Burning Springs-Volcano anticlinal of West Virginia, which along its highest crest in Wirt, Wood, and Pleasants counties brings up to daylight successively the Monongahela, Conemaugh, and Allegheny series, right across the center of the Appalachian field, confirms the story of the drill, since near Petroleum station, where all the measures from the top of the Monongahela series down to the Pottsville are exposed to view, only one coal bed is visible, and it is only four feet thick, impure, and split into two practically worthless divisions by 6 to 8 feet of slate. Your speaker has personally examined the rock materials brought up by the sand pump while the drill was passing through the Allegheny beds in several wells from the region of Pittsburg southwestward across western Pennsylvania, West Virginia, southeastern Ohio, and on to the Big Sandy river at the Kentucky line in Wayne county, with the result that over a belt having a width of 40 to 50 miles at the Pittsburg end, and practically the same on the Big Sandy, and swelling out to 100 miles or more near its center at the longitude of the Little Kanawha river, there is practically no commercial coal, as we know that term now, in the entire Allegheny series.

Extent of Reduction of the productive Areas

The effect of this barren zone on West Virginia's productive coal area is to reduce it from 17,000 square miles, as usually given in statistical tables, to only about half that size, and the tonnage, as recently estimated by Mr M. R. Campbell, of the United States Geological Survey, from 231,000,000,000 to only about 60,000,000,000 tons of first-class available fuel, after providing for the necessary waste in mining, or less than one-half of Mr Campbell's estimate for that state.

The 112,000,000,000 tons of bituminous coal originally existing in Pennsylvania and 86,000,000,000 in Ohio, as estimated by Campbell, are also both much too great, on account of this barren zone in these states. It is quite certain that Pennsylvania will not furnish much more than 40,000,000,000 tons and Ohio probably not more than 25,000,000,000 tons of commercial bituminous coal; so that the three great coal states of the northern Appalachian field, namely, Pennsylvania, Ohio, and West Virginia, will together produce only about 125,000,000,000 tons of good coal and probably 50,000,000,000 tons of an inferior grade, instead of the much larger quantity indicated by Mr Campbell's figures, which are evidently based upon the old supposition that this barren area would hold as much coal as any other portion of the Appalachian field.

METHOD OF DEPOSITION OF THE COAL

From this brief statement of the facts in the case it would appear that the several coal formations, beginning with the oldest—Pocahontas, New River, Kanawha, Allegheny, Conemaugh, and Monongahela—were deposited in narrow belts or fringes, 20 to 30 miles in breadth, around the borders of the great Appalachian basin, each higher series extending farther toward the center of the trough than its predecessor. This condition of affairs is shown by the distribution of the colors on the West Virginia coal map, and which in its uncolored portion also indicates the central barren zone. The query naturally arises: Why were no valuable coal beds formed in this great central trough, where the older geologists and many of the younger ones, it appears, supposed the coal beds would be thickest and most numerous? The question is a puzzling one, but this absence of valuable coal deposits is due most probably to the fact that the central region of the Appalachian coal field was covered with water to such a depth that vegetation could not secure a foothold, and hence while sediments accumulated there to practically the same thickness as in other portions of the basin, they consist only of shales, sandstones, and limestones, the latter being in greater proportion than where the coal accumulated in commercial quantity. Of course, there will be some islands of commercial coal in this long and broad barren zone, but they will be local and of small extent.

DURATION OF THE NORTHERN APPALACHIAN FIELD

This shortage of coal brings to the citizens of the Pittsburg region, the present manufacturing center of the world, the most serious problem that has ever confronted them. They have been told that they originally had 430,000,000,000 tons of coal in the three states that surround them, and that it would suffice for 150 to 200 years, while the truth is they have only about one-half of that amount, and with the present wasteful mining methods it will last only 50 years. If this waste continues, some of you in this audience will see the finish in the northern Appalachian field of all cheap and easily obtained coal. Many of you do not credit these statements. They are capable of demonstration to those whose minds are open to reason and the irresistible logic of facts.

The area of the great Pittsburg bed, that wonderful coal seam to which Pittsburg owes its very existence, is known almost to the acre. Pennsylvania had remaining 1,090,000 acres of it at the beginning of 1908, and she has several thousand acres less now, since her annual production from this one coal bed is approximately 95,000,000 tons. This represents an exhaustion of over 1,000 acres every month of the year, because the best mining engineers of Pennsylvania have succeeded in saving and utilizing only 8,000 tons of coal to the acre, of the 12,000 to 15,000 that are present in the Pittsburg vein. Hence, should there be no increase in production over the present, this famous coal bed would be entirely exhausted from the state of Pennsylvania within 80 to 90 years. But what reason is there for not believing that every normal year will record its regular increase, until in 10 to 12 years at most Pennsylvania will have doubled her present output of Pittsburg coal? West Virginia has only about the same acreage of this great coal bed as Pennsylvania, while Ohio's entire area will be practically gone in 25 years. Hence one can readily perceive that, with only a century's supply at the present rate of mining and in view of the greatly increased production which can not fail to come with our growth in population, 50 years is a liberal estimate for the life of the Pittsburg coal bed. The same causes will in approximately that time exhaust all of the cheaply mined thin veins in the Allegheny series of Pennsylvania, Ohio, and northern West Virginia, and Pittsburg's industries will have entered upon the expensive method of mining coal by deep shafts to beds of inferior quality, of only one to two feet in thickness, and of attempting to recover at great expense the many millions of tons of good fuel already left in the pillars, roofs, and bottoms of long abandoned mines. This is no fairy story. It is as sure to come to pass at approximately 50 years in the future, if present wasteful methods continue, as that the sun will rise tomorrow.

Present Waste of Fuel

It can do no harm to recall some of the sins of waste committed in the past, since many of these still persist. The citizens of Pennsylvania, and especially of the Pittsburg district, have already wasted more of their precious fuel supplies, both solid and gaseous, than they have ever used. More than thirty thousand beehive ovens continue to consume, almost within sight of their great factories, one-third of the power and all of the precious by-products locked up in the finest bed of coal the world has ever known, and of which, as we have seen, they have such a limited supply. The quantity of natural gas, that best of all the fuels, which western Pennsylvania has wasted from the many thousands of wells drilled within her borders, vastly exceeds in value all the petroleum she has ever produced. Not satisfied with thus despoiling their own fair commonwealth of its most precious fuel possession, some of the most powerful corporations, with headquarters in Pittsburg, have been the principal agents in wasting unnumbered billions of cubic feet of this precious fuel in the sister states of Ohio and West Virginia. The general superintendent of one of the great gas companies told me only a few days ago that he had personal knowledge of one well in West Virginia from which 12,000,000 feet of gas escaped daily in producing only four barrels of oil, and this spectacle of wasting the heating value of 12,000 bushels of coal daily, together with the power to deliver itself free of charges for transportation to Pittsburg's factories, was at that time not an isolated case, but only one of hundreds. During this riot of waste one of these great gas companies put into its lines in West Virginia nearly 100,000,000 cubic feet of gas daily and delivered in Pittsburg much less than half that quantity, the larger portion having escaped into the air through the defective joints of cheap and imperfect pipe-line construction. An enormous waste of gaseous fuel is still an incident of oil production in Pennsylvania, as well as in Ohio and West Virginia, and will probably so continue to the end of the chapter, largely because a few influential citizens of Pennsylvania, Ohio, and New York always oppose any attempt to prevent this crime against these commonwealths. A great portion of this wasted gas in West Virginia and Ohio was safely stored by nature, under immense pressure, in the immediate pathway of this barren coal zone, and there can be no doubt that its heating value, if properly utilized, would have much more than replaced the missing coal beds, and thus to that extent delayed the end of cheap fuel in the Pittsburg district.

Danger of Catastrophes

The recent awful catastrophe at Marianna is most disquieting to thinking minds. Disquieting, not alone for the frightful loss of precious lives from the ranks of the brave toilers in a most dangerous occupation, in which the men of skill are all too few, but also for the dread suspicion which arises concerning the future of deep mining in this richest zone of coal. Harwick, Ellsworth, Naomi, Monongah, Darr, Marianna are all within the regions of great deposits of natural gas. Can it be possible that in such situations this volatile substance, released from its long prison by the thousands of oil and gas wells drilled to the deeply buried reservoirs of gaseous fuel, has permeated these mines in large quantity through the ever-present fissures of the earth's stony crust?

At the White House conference of governors, called last May by our illustrious President to take stock of the fast disappearing natural resources of the nation, and to advise with him concerning ways and means to conserve the same, your speaker called attention to this "sword of Damocles," an ever-impending peril to deep mining over the oil and gas areas, and to the unknown waste of coal and precious lives that may possibly result therefrom. At least three-fourths of the entire area of Pittsburg coal remaining unmined in Pennsylvania, Ohio, and West Virginia is within this dangerous zone. Of the thousands of oil and gas wells drilled in this great area stretching from the Pittsburg region southwestward across Pennsylvania, West Virginia, and southeastern Ohio, hundreds of which have been abandoned in each of these three states and the casing removed, probably not a single one has been so located by public charts accessible to coal operators that its presence could be learned and its danger guarded against after the farmers have cleared away the rubbish of derrick and drill and recovered the poisoned soil for grazing or other agricultural purposes. There would have been perils enough in this deeply buried Pittsburg coal area from the inflammable gases already present in the coal itself, if not a single oil or gas well had ever been drilled to these great underlying reservoirs to release, when abandoned, the deadly forces of explosive gas into the very midst of the workers, against which neither the skill of the miner nor the science of the engineer seems able to cope. It is barely possible that the oil and gas producers have thus through abandoned wells added so greatly to the perils of deep mining that large areas of this matchless Pittsburg coal, as well as any other beds which might underlie it in this broad oil and gas belt southwest from Pittsburg, will be practically irrecoverable except at enormous expense of life and treasure. It is needless to comment upon the additional fuel shortage which such a condition would mean to Pittsburg's iron and steel industries. The mere mention of the possibility of this peril ought to be sufficient to put every patriotic citizen on guard against increasing this danger. Not a single string of casing that has penetrated the productive coal measures in the oil or gas regions of the states where natural gas is encountered in any appreciable quantity should ever be pulled out until the underlying coal has been removed. The oil producers are robbing the entire country of its precious fuel gases. Why should they be permitted also to endanger its solid fuels? Here is some work for the governors and legislatures of Pennsylvania, Ohio, West Virginia, and Kentucky that could bring no harm to legitimate oil and gas interests and which may result in an immense saving of life as well as of fuel resources.

NEED OF CONSERVATION

What moral should be drawn from these facts? That homely adage of our forefathers, "Needless waste brings woeful want," is just as true for communities, states, and nations as for individuals. The story of "Coal Oil Johnny" is being reenacted by the Pittsburg district and many other districts of our country on an enormous scale, and the final results, although a little longer delayed, can not fail to be similar. On the one hand we perceive our fuel resources reduced by this barren zone to one-half of what were supposed to be readily and cheaply accessible, and on the other, these resources so greatly depleted by unbridled waste that in only a few years at most cheap fuel will have passed into history from this great district.

Disguise it as we may, the picture is not a pleasing one. The great engineers and captains of industry, whose skill and genius, aided by an unrivaled wealth of cheap fuel and the protecting ægis of a wise and generous government, have centered here the iron and steel business of the world, should not glance at the picture and turn lightly away to forget it in the busy hum of furnace and forge. These wonderful industries should remain here and prosper not a few decades, but for centuries. But just as surely as the successful past and glorious present have been founded upon unrivaled resources in cheap fuel, so surely will these great industries decline and die with its disappearance. "Mene, Mene, Tekel, Upharsin" will be written large over the gateways of the Pittsburg district before the present century closes, unless the men who own the mines and factories awake at once to the danger that portends.

What will it profit these industries that enormous coal deposits exist in Wyoming, North Dakota, Montana, and far away Alaska, as well as in other portions of the distant west, when a freight cost of many dollars per ton intervenes? No, these western coal fields are not for Pittsburg. Nature has forbidden it by barriers which the skill of man can never hope to conquer. When the coal in the Appalachian field is gone, no other field can take its place in Pittsburg's industrial life.

Every citizen of our beloved union is interested in perpetuating as long as possible the giant industries that have sprung into existence around the home of Father Pitt. When the mighty pulsations of this industrial life slow down even temporarily, lethargy and palsy strike every artery of trade and commerce on the continent. The postponement or prevention of the evil day when these great industries shall close for want of power is worthy of the best thought of every patriotic American.

Remedy for the Evils of Waste

What is the remedy? What is possible to be done in order to postpone indefinitely this dreaded day, so fateful to industrial life? The answer may be summed up in two words—Stop wastes. Not alone waste of natural gas, waste in mining, but all other needless wastes. Why should the flaming throats of so many wasteful coke ovens continue to vomit skyward such enormous volumes of precious gaseous fuel, with its clouds of carbon to pollute the air, stifle vegetation, and render life a burden, when all of this wasted energy will so soon be needed in our unrivaled factories? True, your furnace managers may say the coke from the beehive oven is superior in structure and reducing capacity to that of the by-product process. But is this superiority sufficiently great to warrant the waste of so much heat, and all of the other precious by-products which our European cousins find so much profit in manufacturing and selling to us? Are not our engineers equal to the task of manufacturing a first-class furnace coke without such an enormous waste of values? Are they less skillful than their German and English brothers?

Why should we retain the steam-engine, to consume with frightful speed so much of our finest fuel, when much more power can be obtained by the use of the gas engine from an equal weight of impure or low grade coal? Fortunate would it be for our future if some master genius could arise in the great iron and steel industries who would at one stroke arrange to relegate both the steam-engine and the beehive coke oven to the junk heap of the wasteful past, like McCrea and his predecessor, the gifted Cassatt, have undertaken to do with the steam locomotive on one of the world's greatest railways.

Again, why should the Pittsburg district permit these acres of coal barges, loaded with precious black diamonds, the heart of the finest coal bed in the world, mined from its immediate hills, to float through its gates *down* to other marts at a minimum profit to any one owing to enormous losses by flood and collision, when it is absolutely certain that before the century closes the coal from eastern Kentucky and southern West Virginia will be towed *up* the Ohio to replace what should never have been taken away. Would it not be prudent and the part of far-seeing business wisdom to let the Great Kanawha and Big Sandy coal fields possess these southern markets, to which they are so much more cheaply accessible, rather than sell at a small profit today what will be bought back in the near tomorrow at triple or even quadruple the present selling price? The coal in the Appalachian field is the only large body of first-class coking fuel on the continent, and the first duty of those who control the bulk of the enormous iron and steel industries of this district is to conserve all that is possible of this precious fuel for that particular purpose.

Another form of wasted energy not so apparent to the eye, but which in the aggregate probably amounts to much more annually than all other forms of energy, both consumed and wasted, is the waste of water, which the nation permits to pass unhindered to the sea, often destroying in a year enough property in the Pittsburg district and between there and Cairo to pay the entire cost of control and utilization. With the waste and disappearance of our forests, these periodical floods are certain to increase in destructiveness. Why should this now worse than wasted power, all easily within the limits of electrical transmission, not be so stored, controlled, and utilized that we could not only have navigable rivers from Pittsburg to the Gulf the most of the year, upon which to distribute cheaply the products of the mills and factories, but could also thereby greatly prolong the life and growth of our famous industries?

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AFTONIAN MAMMALIAN FAUNA[1]

BY SAMUEL CALVIN

(Presented by title before the Society December 31, 1908)

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STRATIGRAPHIC POSITION OF THE AFTONIAN DEPOSITS

Between the two older drift sheets of Iowa, known respectively as the pre-Kansan and the Kansan, there are many evidences of a long interval of mild climate. Such an interval is indicated by intercalated weathered zones, soil bands, peat beds, buried forests, and aqueous deposits of sand and gravel. Chamberlin pointed out the interglacial position of the extensive gravel beds at Afton Junction and Thayer and gave the name *Aftonian*[2] to the interval which they in part represent. The writer, discussing the age of these gravels in the Proceedings of the Davenport Academy of Sciences, was led to conclude that they are the work of streams which had their origin in the rapid melting of the pre-Kansan ice, and that they belong in reality to the closing phase of the pre-Kansan glaciation.[3] In rapidly disappearing glaciers there was offered a reasonable explanation of vigorous, swollen streams such as might carry and deposit loads of gravel, and no efficient cause of such floods at any time between the beginning and the close of the Aftonian interval was so readily conceivable. Work on the gravel pits at Afton Junction and Thayer was stopped some years before the deposits came under the observation of geologists. If fossil bones were found during the progress of the excavation, there was no record of the fact. In view of the conclusion as to the conditions under which the gravels were laid down, contemporary faunas were regarded as impossible and no inquiries were made. Bones and teeth of post-Tertiary mammals have been found in the surficial deposits of Iowa, but they have usually been referred in a broad way to the Pleistocene. The many known Aftonian peat beds have so far yielded no mammalian remains, and very few mammals which could be referred definitely to any given stage of the Pleistocene have been heretofore discovered in the area between the two great rivers.[4]

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[1] Manuscript received by the Secretary of the Society December 31, 1908.

[2] See Journal of Geology, vol. iii, 1895, p. 272. When this editorial was written it was believed that the till beneath the gravels was the Kansan and that above them the Iowan. For later discussion and reference of the gravels to their true position beneath the Kansan, see the same journal, vol. iv, p. 872.

Relation of the Gravels, in Time, to the Aftonian Interval

Within the past few months, in Harrison, Monona, and other western counties of Iowa, Shimek has found stratified sands and gravels of great thickness and extent lying between the pre-Kansan and the Kansan drift.[5] The stratigraphic position is clear and well established; the gravels are Aftonian in age, but they contain evidence that they were not deposited until some time after the old pre-Kansan ice-sheet had completely disappeared. In the light of this evidence, it may be necessary to revise the opinion concerning the precise date of deposition of the Thayer and Afton Junction beds, expressed in the Proceedings of the Davenport Academy of Sciences. The new evidence comes in the form of a fairly rich mammalian fauna that must have been contemporary with the deposition of the gravels, but which certainly did not live in the wet, chill, verdureless region that coexisted with the melting of the pre-Kansan ice. As noted

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[3] Samuel Calvin: The Aftonian gravels and their relation to the drift sheets in the region about Afton Junction and Thayer. Proceedings of the Davenport Academy of Sciences, vol. x, 1905, pp. 18-30, plates i–vii.

[4] In the third edition of The Great Ice Age, by James Geikie, 1895, p. 759, Professor Chamberlin refers to *Equus complicatus*, *Lepus sylvaticus*, and *Mephitis mephitica* as occurring in interglacial deposits in Iowa, but the horizon is not definitely stated. More definite is Leverett's reference to the occurrence of *Lepus* and *Mephitis* at the Yarmouth horizon, between the Kansan and the Illinoian drift sheets, near Yarmouth, Iowa. See Proceedings of the Iowa Academy of Sciences, vol. v, 1898, p. 82.

[5] B. Shimek: Aftonian sands and gravel in western Iowa. Science, new series, vol. xxviii, December 25, 1908, p. 923.

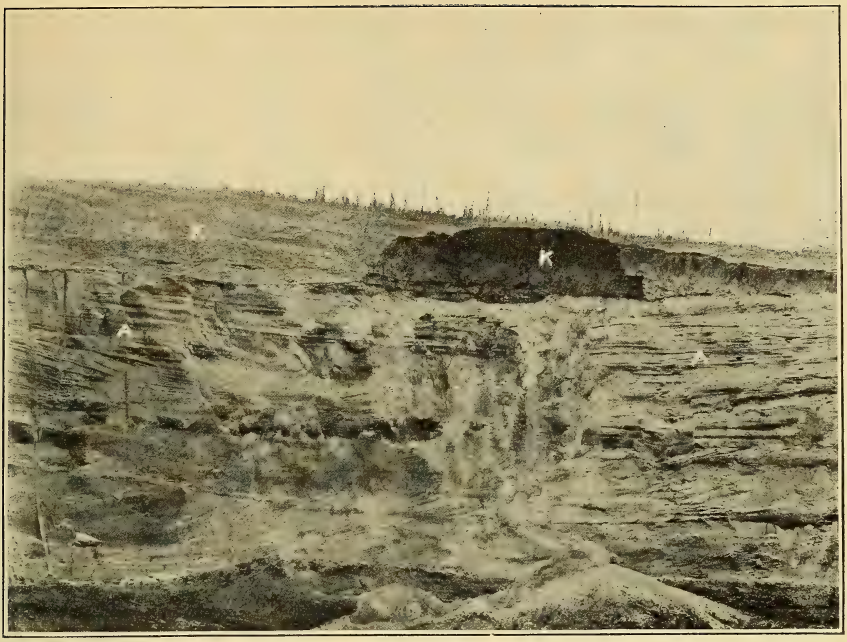


FIGURE 1.—THE COX GRAVEL PIT AT MISSOURI VALLEY, IOWA
Showing (A) Aftonian gravels overlain by (K) Kansan drift

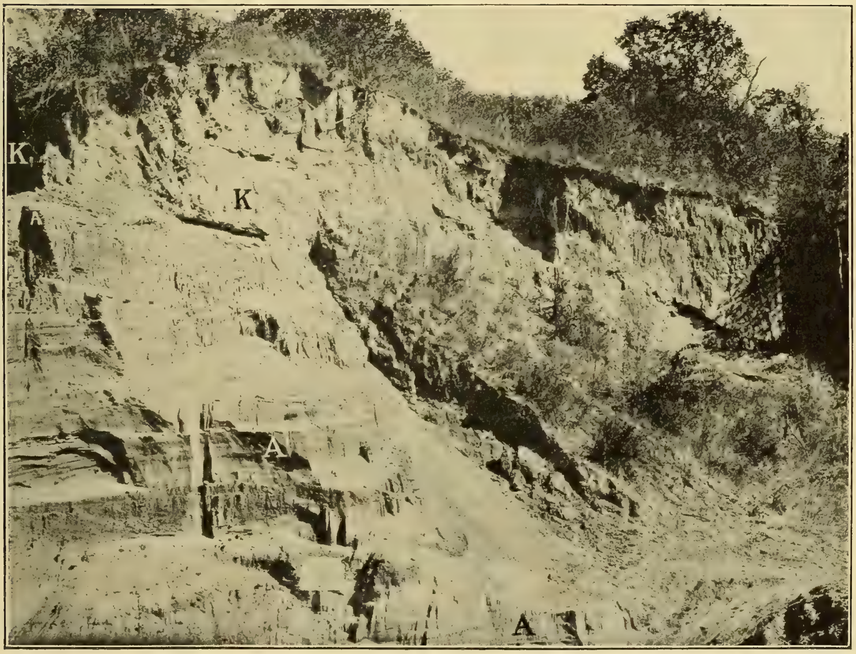
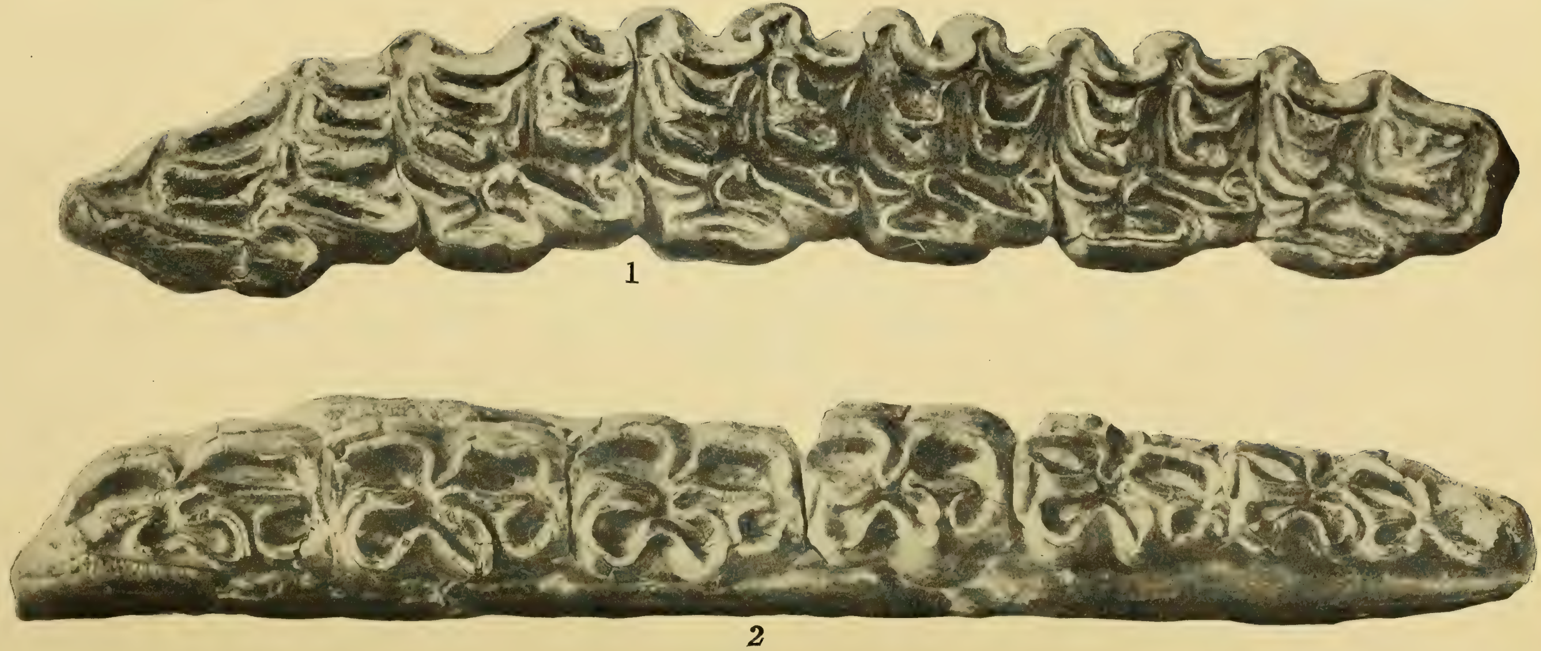


FIGURE 2.—THE PEYTON GRAVEL PIT NEAR PISGAH, IOWA
Showing (A) and (K) in the same relations as in figure 1

THE COX AND PEYTON GRAVEL PITS



TEETH OF THE GLADWIN HORSE

Upper and lower molar-premolar teeth of the Gladwin horse, *Equus scotti* Gidley, from Aftonian silt in section 35, Lyons township, Mills county, Iowa. The figures are natural size. The lower series originally had more curvature, a fact indicated by the form of the open spaces on each side of some of the teeth, p_4, for example. Note the thickness of the lower teeth and the thickness of the enamel.

by Shimek in the article cited, the beds contain the shells of river mollusks belonging to species still living in Iowa; all the evidence shows that the climate was comparatively mild, and that the streams which carried and distributed the fluvial deposits, the streams which transported the mammalian remains and distributed the shells of the river mollusks, were not a product of melting pre-Kansan glaciers. The mammals are represented by bones and teeth in such numbers, in such a state of preservation, and are found at so many widely scattered exposures along different stream valleys as to make it certain that they are not mere chance inclusions washed out of preexisting drift or out of preglacial deposits. It is worthy of note that the mammals consist of large herbivores. There are horses of at least two different species, one species of camel, the great stag, Cervalces, two elephants, the common Pleistocene mastodon, and at least one large Edentate, Mylodon. There are bones and fragments of bones that have not been identified. The great quantity of well preserved material would imply that the uplands between the stream valleys were densely populated, for only a small proportion of the animals that lived and died in the region would be represented by skeletons coming within the reach of floods. To supply these great herbivores with food required an abundance of vegetation such as could not be developed until some time after the pre-Kansan ice and all its climatic effects had disappeared from southwestern Iowa.

LOCALITIES

The fossil remains under consideration have come almost exclusively from the western slope of Iowa, the Aftonian beds having been exposed in the process of valley-making by the streams draining into the Missouri river. It is now known that Aftonian deposits occur at intervals all the way from Sioux City to Hamburg, but the valleys which have thus far received the greatest attention are those of Maple, Little Sioux, Soldier, and Boyer rivers. Gravels have been worked on a commercial scale along the Boyer, and mammalian remains have been uncovered at Denison, Logan, and Missouri Valley. At the point last named the most important is the Cox pit, which, by reason of the greater amount of work done in it, has furnished the larger number of the specimens referred to in this paper (plate 16, figure 1).

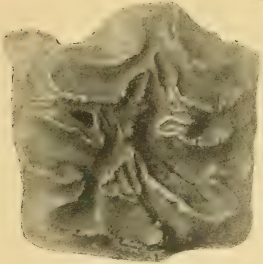
The Peyton gravel pit, located about a mile southwest of Pisgah, has been the most productive of the Aftonian exposures in the valley of the Soldier river (plate 16, figure 2). In the bluff on the east side of the Little Sioux river, a few rods south of the Monona-Harrison county line, there is a fine exposure of Aftonian gravels which has been worked intermittently and chiefly for road materials. Nothing is known of the finding of fossil remains at this point, but the outcrop is of especial interest for the reason that the overlying Kansan and the underlying pre-Kansan drift sheets are both exposed in place, with the weathered and ferruginous Aftonian between them. At Pisgah and Missouri Valley the till below the Aftonian beds is not in sight.

Farther up the valley of the Little Sioux, at Turin, in Monona county, some good fossil remains have been found, and there are pits near Castanea and Mapleton, in the Maple valley, which have produced bones of Aftonian mammals.

A very promising area, which has not yet been carefully investigated, embraces a number of sections in the southeast corner of Lyons township, Mills county, and the adjacent sections in the northeast part of Scott township, Fremont county. The Aftonian gravels occur in natural exposures within this area at a number of points, and they have been penetrated in farm wells which have gone down through the Kansan drift. There are trustworthy reports that mammalian bones have been taken from the gravels in some of the wells, and a number of finds have been made in the gravel pits, which are operated here on a relatively small scale. A complete set of left molars of a large horse, upper and lower, was found by Mr E. L. Gladwin while grading a road in section 35, Lyons township, Mills county, and is now in possession of the writer. A considerable portion of the skeleton was present, but the bones were too soft for preservation. Both upper and lower series of this fine set is illustrated in plate 17. The Gladwin horse was found in a fine blue clay, a bed of silt, that here in places overlies the gravels but is of the same age. Similar silts occur with the gravels, but interbedded with them, at Missouri Valley and Pisgah, in Harrison county.

The Aftonian Horses

In the collections under consideration horses are represented by a much larger number of bones and teeth than any of the other types of Aftonian mammals. There are bones from nearly all parts of the skeleton, but leg bones and foot bones are most common and most significant. Among the teeth there are eighteen superior molars and premolars and about an equal number from the lower series. The Gladwin set is the only one that is complete; the other teeth show great variations in the amount of wear and in minor details, and it is quite certain that they represent a number of individuals. At least two species seem to be clearly indicated. In one the teeth are larger than those of the modern species, as is shown by the following comparisons and measurements of the upper molars of the Gladwin horse. Comparison is made with the



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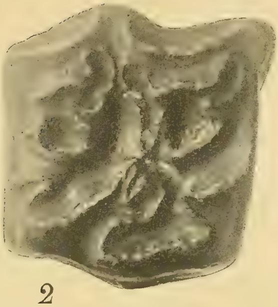

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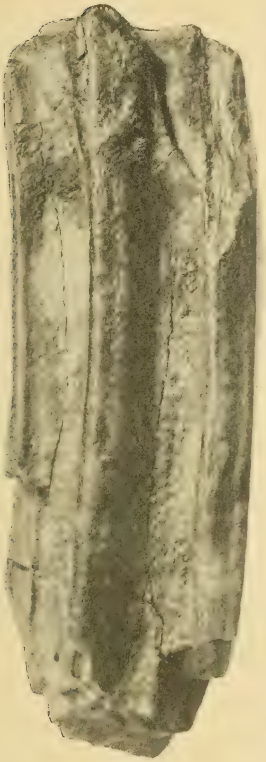

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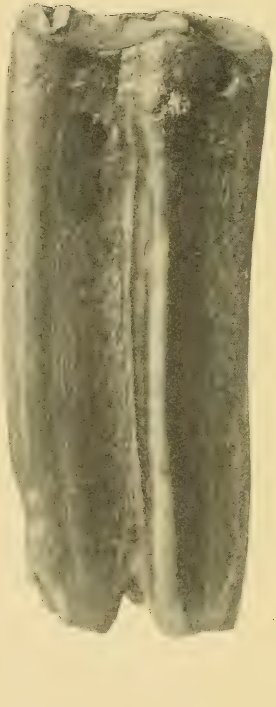

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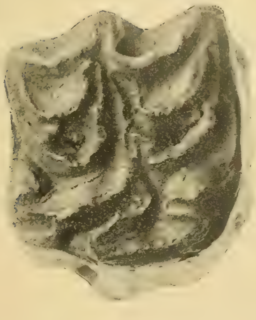

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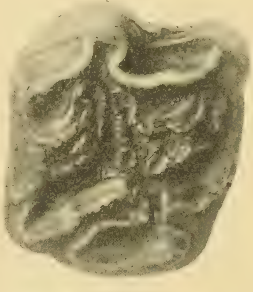

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SUPERIOR GRINDERS OF EQUUS SCOTTI GIDLEY

From the Cox pit, Missouri Valley. Figures 1, 3. Grinding surface and outer side of tooth number 116. Figures 2, 4. Same views of tooth number 117. Figures 5, 6. Grinding surfaces of teeth numbers 119 and 118. All figures natural size.

measurements of the teeth of the domestic species, expressed in millimeters, as given by Gidley in the table on page 98 of volume xiv of the Bulletin of the American Museum of Natural History. Only the transverse diameters are compared, but the other dimensions show corresponding differences in size. In the case of the teeth of the Gladwin horse, to quote from Gidley, "the transverse diameters were measured across from the exterior ridge of the mesostyle to the exterior wall of the posterior lobe of the protocone, exclusive of cement." In the Gladwin horse fully half the original length of the teeth has been worn away. The antero-posterior dimensions of the entire series of superior grinders, measured in a straight line from the sharp, anterior enamel fold of p^2 to the posterior, outer fold of m^3, is 187 millimeters. The antero-posterior dimensions of the individual teeth, following the outer curve of the series, but inside the metastyle and parastyle, are: p^2, 43.5 millimeters; p^3, 33 millimeters; p^4, 31 millimeters; m^1, 25 millimeters; m^2, 26 millimeters, and m^3, 32 millimeters. This gives a total length of the series around the outer curve, but inside the external styloid ridges, of 190.5 millimeters.

Table showing comparative transverse Diameters of the Teeth of the Gladwin Horse.

	p^2.	p^3.	p^4.	m^1.	m^2.	m^3.
Gidley's largest draft horse	28.0	30.0	28.5	28.0	26.5	23.0
Gladwin fossil horse	28.7	32.0	32.5	30.0	28.5	26.0
Differences	.7	2.0	4.0	2.0	2.0	3.0
Average of the 8 horses recorded in Gidley's table	24.8	26.1	26.9	26.0	25.4	22.2
Differences when the Gladwin horse is compared with the average of Gidley's 8 horses	3.9	5.9	5.6	4.0	3.1	3.8

There are a number of teeth from the Cox pit at Missouri Valley, and one from Turin, which agree in dimensions with the larger teeth of the Gladwin horse, and are evidently from the same species, if transverse diameters may be taken as a guide. These may be noted in tabular form as follows:

Catalogue number.	Reference to illustration.	Transverse diameter.	Antero-posterior diameter.	Length.
116	Plate 18, figures 1, 3	33.0	33.0	95
117	Plate 18, figures 2, 4	33.5	35.0	82
118	Plate 18, figure 6	32.0	32.0	38
119	Plate 18, figure 5	31.5	29.0	50
125	(Not illustrated)	31.0	30.0	62
136	(From Turin, not illustrated)	33.0	35.0	80

An imperfect second upper premolar, with the thin, anterior edge broken away and having a transverse diameter of 29 millimeters, belongs in this group of large teeth. Nearly one-third of the crown has been worn off by use; the part remaining measures 65 millimeters in length.

Among the recognized species of Pleistocene horses the teeth of the Gladwin horse and the others above noted agree best in size with *Equus scotti* Gidley, from the Sheridan beds, Rock Creek, Brisco county, Texas,[6] though tooth number 117 is practically identical in size and other details with the superior third and fourth premolars referred by Gidley to *Equus pacificus* Leidy.[7] Comparing the Gladwin teeth with the measurements given for *Equus scotti* in the American Museum Bulletin, volume xiv, page 136, the close agreement becomes apparent:

	p^2.	p^3.	p^4.	m^1.	m.	m^3.
Antero-posterior diameter :						
Equus scotti	43.0	34	33	30	31	31
Gladwin horse	43.5	33	31	25	26	32
Transverse diameter :						
Equus scotti	30.5	33.0	33.0	30	29.0	24
Gladwin horse	28.7	32.0	32.5	30	28.5	26

The differences that appear in making these comparisons may be accounted for on the basis (1) of individual variations and (2) of differences in the amount of wear which the teeth of the two animals has undergone. The measurements of *Equus scotti* given on page 136 of the work cited are those of an individual "in which all the teeth have come into full use," but presumably an animal comparatively young. The teeth of the Gladwin horse, on the other hand, have been worn down to about half of their original length. The greatest discrepancy appears in the antero-posterior diameters of m^1 and m^2 and in the transverse diameters of p^2 and m^3. Applying Gidley's "Laws governing the changes of diameters of the tooth crowns," formulated on page 99 of the American Museum Bulletin already quoted, the differences are largely, if not wholly, explained. After the molar-premolar series comes into full use, according to law (1), the antero-posterior diameter of each of the intermediate teeth diminishes at first very rapidly, and then more gradually to the roots. Differences even as great as those seen in m^1 and m^2 are to be expected. The antero-posterior diameter of m^3 in the Gladwin horse accords with law (3). The differences in transverse diameters of the first and last teeth of the series exemplifies that part of law (4) which is expressed in the clause "p^2 gradually diminishes, while m^3 increases in

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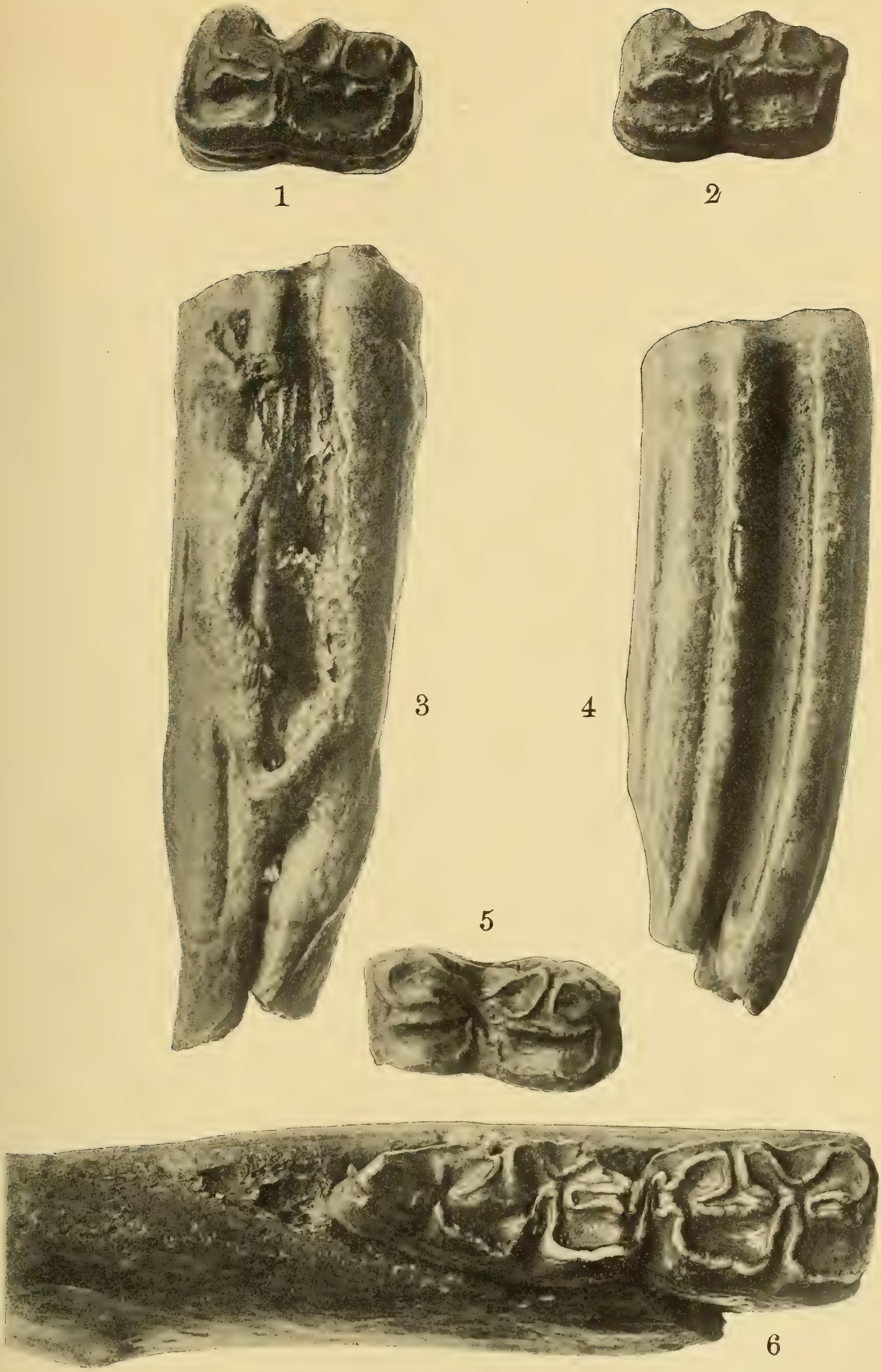
[6] Bulletin of the American Museum of Natural History, vol. xiv, p. 134.

[7] Op. cit., p. 117.



INFERIOR CHEEK TEETH OF FOSSIL HORSES

From the Cox pit, Missouri Valley. Figures 1 and 3 and 2 and 4 illustrate two of the thin, nearly cementless lower teeth with thin, flexuous enamel, referred to *Equus complicatus* Leidy. Figure 5 is a short, well-worn tooth of the same species. The two molars of figure 6 have the same characteristics as the lower teeth of the Gladwin horse, *Equus scotti* (plate 17, figure 2). Natural size.

transverse diameter as the crown wears away." In the present case the teeth are the only parts available for study, but these are in such perfect accord with the teeth of *Equus scotti* Gidley that there need be little hesitation in referring them to that species. *Equus scotti* has been recognized with doubt in collections from the Sheridan beds near Hay Springs, Nebraska,[8] a point farther north than southwestern Iowa and equally as far from the type locality.

The collection contains a few teeth of smaller size, agreeing in dimensions and in the enamel foldings with teeth which have been referred to *Equus complicatus* Leidy. A superior third molar, number 128, from Missouri Valley, shows a very complicated pattern, even though considerably worn. Its dimensions are: transverse diameter, 24 millimeters; antero-posterior diameter, 27 millimeters; length, 60 millimeters. An Aftonian gravel pit at Turin, Iowa, has furnished an imperfect superior molar, number 122, intermediate between the first and the last of the series, but its exact position undetermined, which shows a transverse diameter of 28 millimeters and a length of 70 millimeters. The anterior fourth of the tooth has been split off, but what remains shows very complicated enamel foldings. Another tooth, number 124 (plate 21, figure 3), of somewhat simpler pattern, but still sufficiently intricate to belong to *E. complicatus,* is from the Cox pit at Missouri Valley; it is 28 millimeters in transverse diameter, 29 millimeters antero-posteriorly, and 70 millimeters in length. Tooth number 121 (plate 21, figure 4) is also from the Cox pit; it is 75 millimeters in length, but little worn; the enamel pattern is much simpler than in any of the other teeth so far noted. It agrees with *Equus excelsus* and *E. occidentalis* in the absence "of the little enamel fold near the bottom of the deep valley between the protocone and the hypocone." It is 28.5 millimeters in transverse diameter and 30 millimeters from front to back. In size and pattern, however, this tooth is almost identical with Gidley's figure 3 A, in the American Museum Bulletin, volume xiv, page 97, and this figure is described as a molar of *Equus complicatus.* If the teeth illustrated in figure 3, page 97, and in figure 7, page 109, of the bulletin above quoted may be referred to one species, then all the superior molars from the Aftonian gravels of southwestern Iowa may be arranged under two species distinguished by differences in the size of the teeth, namely, *Equus scotti* Gidley and *Equus complicatus* Leidy.

A specimen which can not with certainty be referred to the Aftonian gravels may be worthy of note. A few years ago there was received from

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[8] W. D. Matthew: List of the Pleistocene fauna from Hay Springs, Nebraska. Bulletin of the American Museum of Natural History, vol. xvi, 1902, p. 317.

Mr John H. Charles, of Sioux City, the fragment of a maxillary with five molar-premolar teeth in place, shown in plate 20. The third molar is missing. The sender was not certain of the exact locality or the geological horizon from which the specimen came, but he added the information that similar teeth had been found in a sand pit along the Big Sioux river. The teeth referred to in this last statement are those mentioned by Bain in his report on the geology of Woodbury county,[9] and pronounced by Cope to be "three left superior molars of the horse, *Equus major* Dek., of Pleistocene age." The sand pit which furnished the teeth submitted to Cope is now known to be a part of the same series of Aftonian deposits recently described from Monona and Harrison counties. The teeth illustrated in plate 20 are, beyond much question, from the Aftonian horizon, though satisfactory proof is lacking; they are more completely worn out than any of the other teeth in the collections, having been cut away by use almost to the fangs. The first molar has actually been ground through to the lower end of the enamel which surrounded the anterior lake. The transverse diameters are: p^2, 24.5 millimeters; p^3, 27 millimeters; p^4, 28 millimeters; m^1, 26 millimeters; m^2, 26 millimeters. Length of the series from the sharp anterior enamel fold of p^2 to the posterior edge of the metastyle of m^2, 137 millimeters; the corresponding dimension in the Gladwin horse, referred to *Equus scotti* Gidley, 155 millimeters. The teeth of the Sioux City horse represent a stage of wear even more advanced than Gidley's A^3, figure 3, page 97, of the bulletin above quoted. Without hesitation they may be referred to the species *Equus complicatus* Leidy, the great simplicity of the enamel pattern being accounted for on the basis of changes due to wear.

Of the lower molar-premolars there are two well marked types which probably correspond to the two species, *Equus scotti* and *Equus complicatus*. The left mandibular series of the Gladwin horse, shown in plate 17, figure 2, illustrates one of these types. The teeth have very thick cementum and are unusually heavy; the transverse diameters measured in millimeters, exclusive of the cementum, are: p_2, 18; p_3, 19; p_4, 21; m_1, 17. The other molars are broken and can not be measured. The thickness of p_4, including cementum, is 24 millimeters. The length of the series antero-posteriorly is 195 millimeters. Another notable feature of these teeth is the great thickness of the enamel. The same thick enamel and massive character are seen in the two inferior molars of figure 6, plate 19, the specimen illustrated being from the Cox pit at Missouri Valley. This specimen may without doubt be referred to the same spe-

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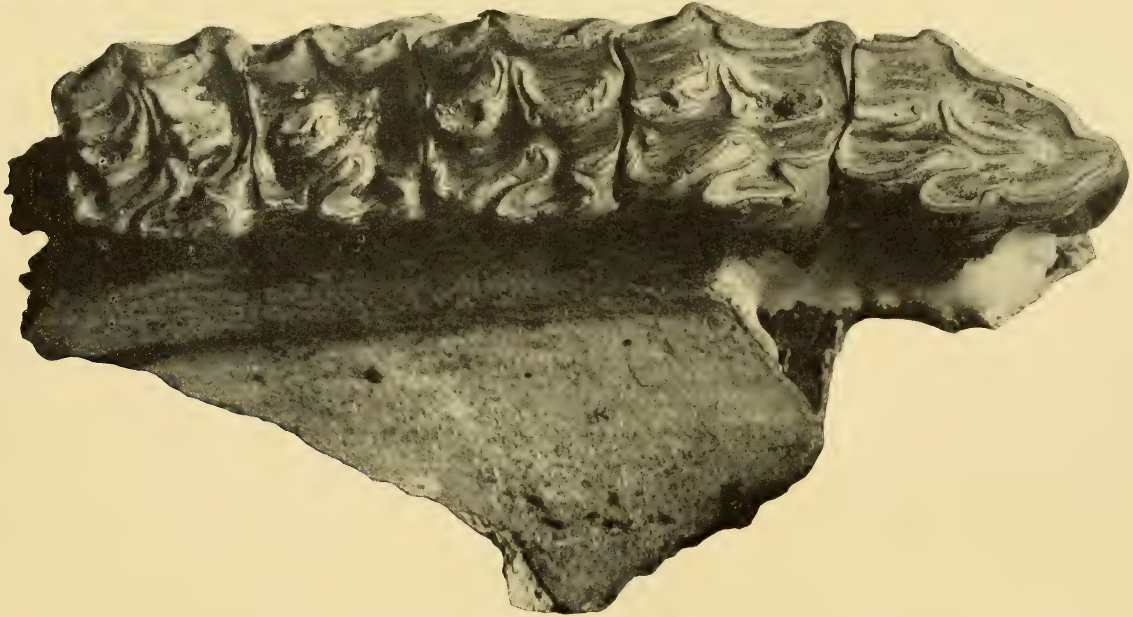
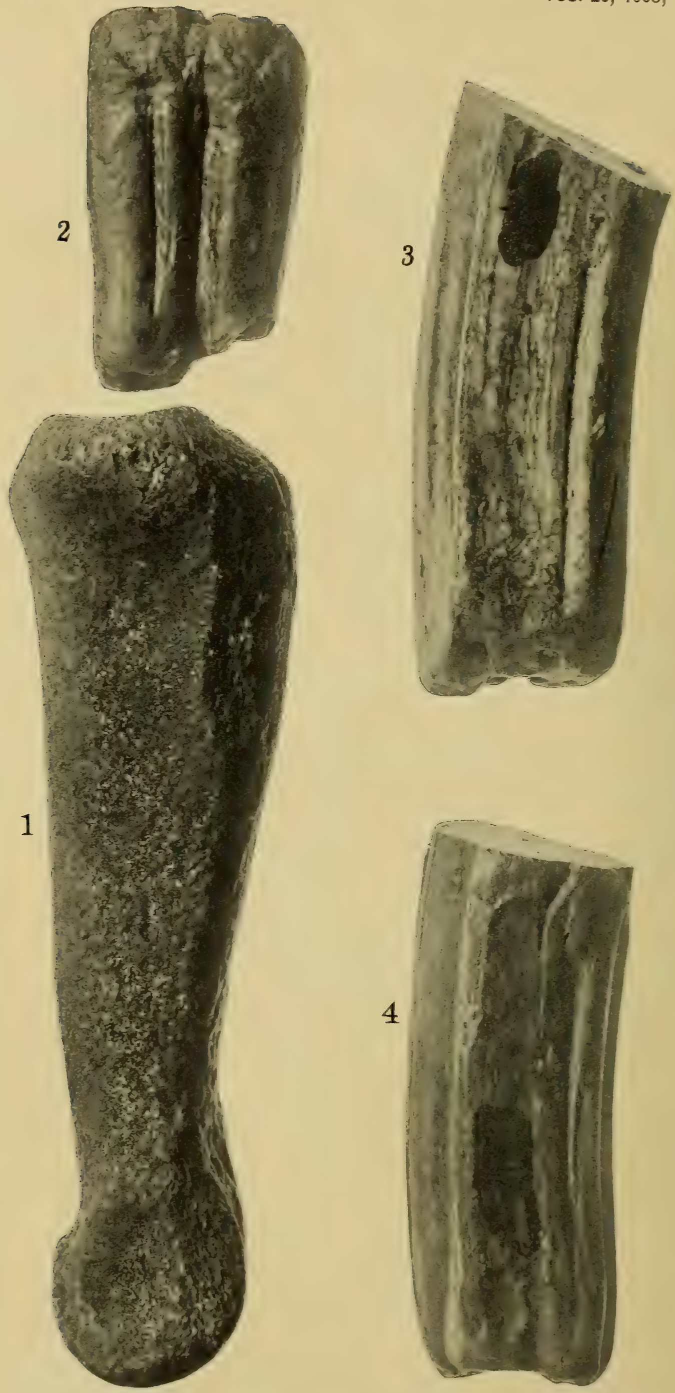
[9] H. Foster Bain: Geology of Woodbury county. Iowa Geological Survey, vol. v, 1896, p. 277. Following Todd, Bain believed this sand was preglacial.



MUCH WORN MOLARS AND PRE-MOLARS OF EQUUS COMPLICATUS LEIDY

Sent from Sioux City, Iowa, but the horizon and locality are not definitely known. Natural size



FOSSILS OF EQUUS COMPLICATUS AND CAMEL

Figure 2. Inferior molar of the thin, cementless type referred to *Equus complicatus* Leidy. Figures 3, 4. Teeth 124 and 121 referred to *Equus complicatus* Leidy. Figure 1. Proximal phalanx of camel, side view. All figures natural size.

cies as the Gladwin horse. All the other inferior molars in the collections belong to the other type. The transverse diameters are less, the cementum very meager, and the enamel is much thinner and more flexuous, as will be apparent on comparing figures 1 and 2, plate 19, with figure 6 of the same plate. That these differences are not dependent on age and wear is indicated by the fact that lower molars equally as short as those of the Gladwin horse agree in essential features with 1 and 2, plate 19. Figure 5 of this plate is an example of a short, well worn, inferior molar of this type. The thinner teeth, with thinner and more flexuous enamel, may be looked upon as teeth belonging to a species quite distinct from the Gladwin horse and may be associated with the superior molars which have been referred to *Equus complicatus.*

Figures 3 and 4, plate 19, are external faces of the thin, almost cementless type of inferior molars, the grinding surfaces of which are shown in figures 1 and 2. The tooth, figure 3, shows the effects of alveolar abscesses from which the animal probably suffered seriously. Whether this disease hastened the death of the individual may not be known, but it is certain that life was cut short from some cause before the teeth were very much worn.

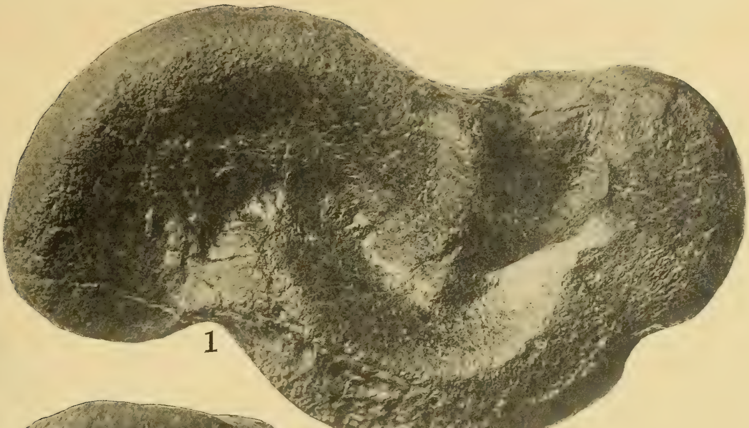
There are many equine bones from the Aftonian beds of Harrison and Monona counties which, while more or less fragmentary, are in a fair state of preservation. There are two humeri, right and left, each lacking the proximal articulation. These indicate an animal about the size of the average modern horse, the radius and ulna of the domestic species fitting perfectly with the radial articulation of the fossil humerus. There are portions of the radius among the fossil bones, four tibiæ, four imperfect metapodials, four first phalanges, and other portions of equine skeletons. The most perfect of the tibiæ is comparatively small. The animal to which it belonged was adult, but the size would indicate a rather small pony. On the other hand, the distal ends of two of the fossil tibiæ are equally as large as the corresponding part of *Equus caballus,* and the same is true of the distal end of a fossil radius. The sides of the broadened articular extremity of the Aftonian radius is abraded, making measurements impossible, but 70 millimeters above the articulation both modern and fossil bones are 60 millimeters in transverse diameter and 35 millimeters in thickness. The fossil metapodials are large and strong and differ in cross-section from the same bone of the domestic species, being more nearly circular in corresponding parts of the shaft. The splint bones were evidently more rudimentary than in the modern horse. Three of the first phalanges are as large as those of the present coach horse; the largest one measures 92 millimeters in length, is 58 millimeters in transverse diameter at the proximal end, 41 millimeters broad at the narrowest part of the shaft, and 51 millimeters at the distal end. A slenderer phalanx, that of an immature individual, is 87 millimeters long and the narrow shaft is 33 millimeters wide. An examination of the equine bones from the Aftonian gravels, entirely apart from the evidence furnished by the teeth, suggests the possibility of at least two Aftonian species, one somewhat smaller than the average horse of today, the other fully equaling the modern horse in size.

The teeth of the Gladwin horse, teeth 116 and 117, shown on plate 18, figures 1 and 2, and the other teeth above referred to *Equus scotti* Gidley are all notably larger than those of *Equus caballus*, while the teeth referred to *Equus complicatus* are about the size of the teeth of the domestic horse. According to Gidley, in the article from the American Museum Bulletin, volume xiv, frequently quoted in this paper, the head and the teeth of the Pleistocene horses were proportionately larger than in the modern species. On page 139 of the bulletin *Equus complicatus* is described as "a species with teeth about the size of those of the ordinary draft horse and of moderately complex pattern, but with the bones of the skeleton about the size of those of the smaller varieties of the western pony." Notwithstanding the large size of the teeth in *Equus scotti*, it is said that "this species represents a horse about the size of the largest western pony." While in all probability the Aftonian horses represent but two species, *Equus complicatus* and *Equus scotti*, the fact should not be overlooked that some of the bones and teeth (figures 2 and 4, plate 18, for example) agree with those of *Equus pacificus*, concerning which it is stated that "the skeleton indicates a horse about the size of the ordinary draft horse, but the skull is proportionately larger." Many of the fossil bones are about the size of those of the ordinary draft horse.

OTHER UNGULATES

Of the ungulates associated with the Aftonian horses, one of the more significant is the camel. This is represented by a single first phalanx which came from the Peyton pit at Pisgah. The bone is shown of natural size in plate 21, figure ~~2~~, and plate 22, figure ~~1~~. It is 127 millimeters long, 36 millimeters in transverse diameter at the proximal end, 31 millimeters across at the distal end, and the smallest diameter of the shaft is 20 millimeters. Other Artiodactyls are indicated by the antler of a large stag from Denison, Iowa, related to *Cervalces americanus*, the distal ends of two metapodials, one of which, lacking a part of the articulation, is shown full size in plate 22, figure 2; and there are two unidenti-

/1 /2



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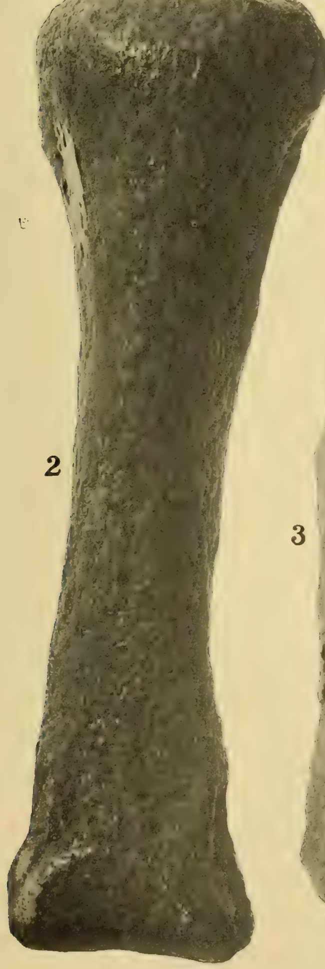

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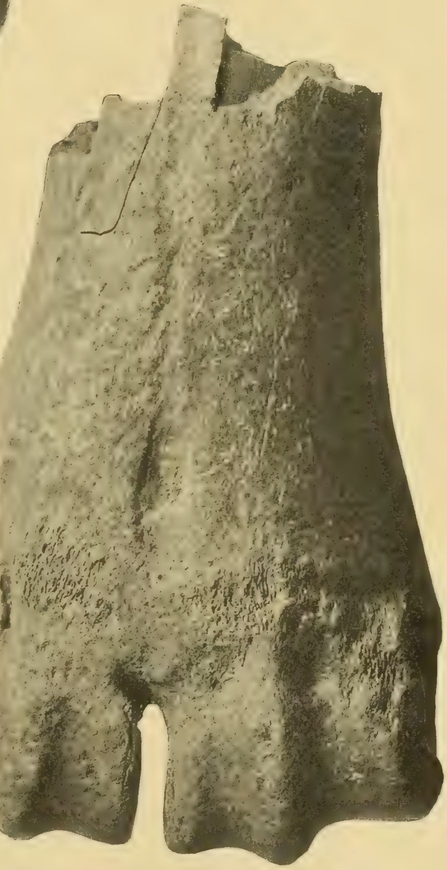
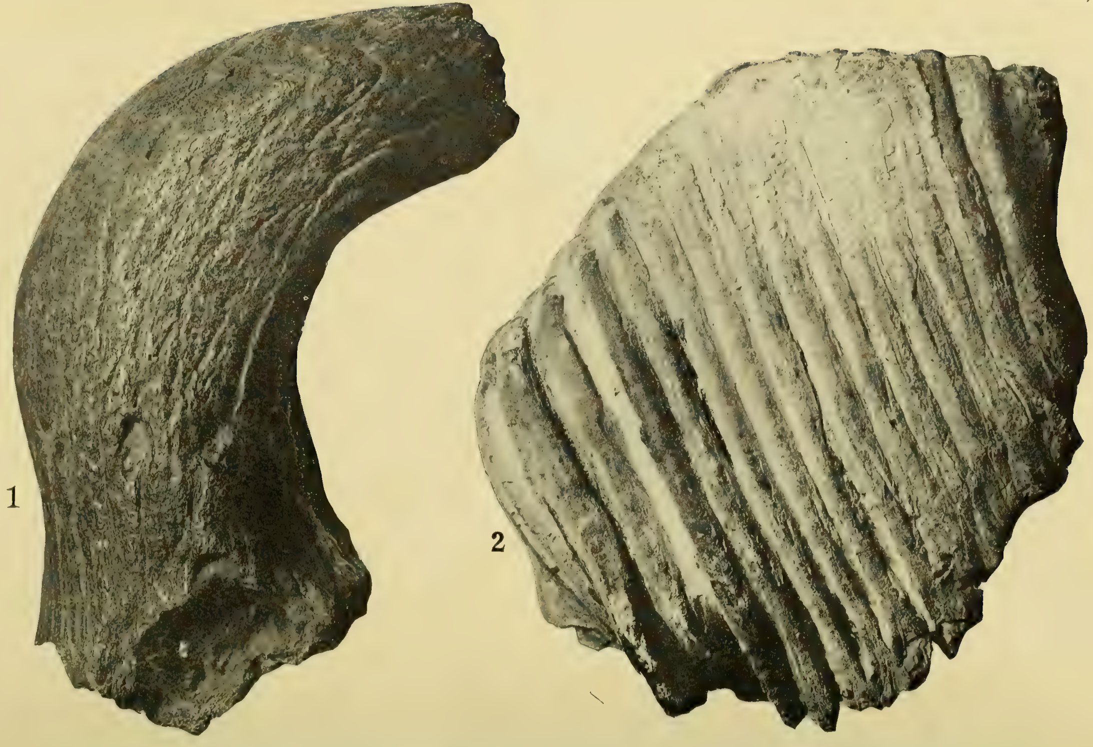


3

FOSSILS OF RUMINANTS

Figure 1. Astragalus of large ruminant; from Cox pit; natural size. Figure 3. Imperfect cannon bone of large ruminant; Cox pit; natural size. Figure 2. First phalanx of camel, front view; Peyton pit; natural size.



FOSSILS OF RUMINANT AND ELEPHAS PRIMIGENIUS

Figure 1. Unidentified horn core, from Cox pit; one-half natural size. Figure 2. Molar of *Elephas primigenius* Blumenbach, from Denison pit; one-half natural size

fied horn cores (plate 23, figure 1). There are two large calcanea and other undetermined bones, probably of Ungulata.

PROBOSCIDEANS

ELEPHANTS

Elephas imperator.—Three elephants are indicated by the collections from the Aftonian gravel pits. A large, slightly worn molar, shown on plate 24 about three-sevenths natural size, has the massive proportions and the coarse ribs which distinguish *Elephas imperator* Leidy. This ponderous, clumsy tooth is from the Peyton pit at Pisgah; it is 290 millimeters (about 11⅜ inches) in length, 108 millimeters (4¼ inches) across the grinding surface, and 265 millimeters (10¾ inches) high, measured between two planes parallel to the grinding surface. The enamel loops, corresponding to the longitudinal ridges on the lateral faces of the tooth, vary in thickness and in the width of the intervening spaces, but on the whole they are more constant in these respects than are those of the tooth illustrated by Holmes[10] and Lucas[11] and which served to re-establish *Elephas imperator* as a valid species. In some parts of the Iowa specimen the ridges are fully an inch in width, the number in 10 inches ranging from 11 to 14, according to the part of the tooth selected for measurement. Besides the large tooth from Pisgah, there is an imperfect lower jaw from the Cox pit at Missouri Valley (plate 25, figure 1) which belongs to this species. In both rami the inner side of the alveolus has been broken away, but the outer wall is intact and shows the broad, vertical grooves corresponding to the wide ridges on the lateral face of the tooth. These are of the same order of magnitude as the ridges of the Pisgah tooth referred to *Elephas imperator*. A large femur to be noted later probably belongs to this species.

Elephas primigenius and *E. columbi.*—There are other and very different elephant teeth in the Pleistocene collections of the University of Iowa in which the number of ridges in 10 inches range from 20 to 25. The exact horizon for some of these is not known, but there is one from the Cox pit showing 20 folds or ridges in the space mentioned, and another from the gravels at Denison showing 25. The specific relationship of these admits of little doubt. Lucas, in the work cited, page 159, specifies 18 ridges in 10 inches as characteristic of *Elephas columbi* and 24 in the same space as marking the molars of *E. primigenius*. Making the necessary allowance for individual variations, the Cox Pit tooth, with its average of two folds to the inch, is referred to *E. columbi,* and the Denison tooth, with two and a half folds to the inch, represents, without doubt, the *E. primigenius.* The last agrees in almost every minute detail with a tooth of *E. primigenius* from Europe.

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[10] William Henry Holmes: Flint implements and fossil remains from a sulphur spring at Afton, Indian Territory. Report of U. S. National Museum for 1901, p. 244, plate 9.

[11] F. A. Lucas: Maryalnd Geological Survey, 1906. Pliocene and Pleistocene mammalia, p. 167, pl. xxxviii, fig. 2.

MASTODON: MAMMUT AMERICANUM

The common American mastodon is represented in the Aftonian collections by a portion of the lower jaw—the symphysis and left ramus, with the last three molars in place (plate 25, figure 2)—and by three separate molars. The jaw is from the Pisgah pit and the separate molars are from Missouri Valley. The Pisgah specimen is massive and shows the deep sockets for the mandibular tusks. The teeth from Missouri Valley are molars 4, 5, and 6, but they are not from the same individual. The fifth molar has the crown completely worn down, and the fangs show effects of absorption; the sixth molar is perfectly developed, but practically unworn.

OTHER PROBOSCIDEAN REMAINS

The other proboscidean fossils worthy of note include fragments of two tusks from Denison, a complete left tibia (plate 25, figure 5) from Missouri Valley, a humerus and a femur (plate 25, figures 4, 6), both imperfect, from Pisgah, and a cervical vertebra (figure 8) from Turin. A scapula, complete when taken from the pit at Missouri Valley, was allowed to crumble to pieces for lack of care by the finders. There are two caudal vertebræ, and a fragment of a pelvis, and, in addition, there is a section of a lower tusk of the mastodon.

The large femur mentioned above is 45 inches long, and yet it lacks all of the enlarged proximal end; it is broken at the thin, flattened part of the shaft below the great trochanter. When complete the length was certainly more than 61 inches, the reported length of the femur of *E. imperator* from Keene, Oklahoma, noted by Lucas on page 168 of the work cited above. The Warren mastodon was among the largest of its species; its femur, complete, is said to be 45 inches in length.[12] The Pisgah femur belonged to an animal larger than the ordinary mastodon, larger than the modern elephant or the northern mammoth, and it is a fair in-

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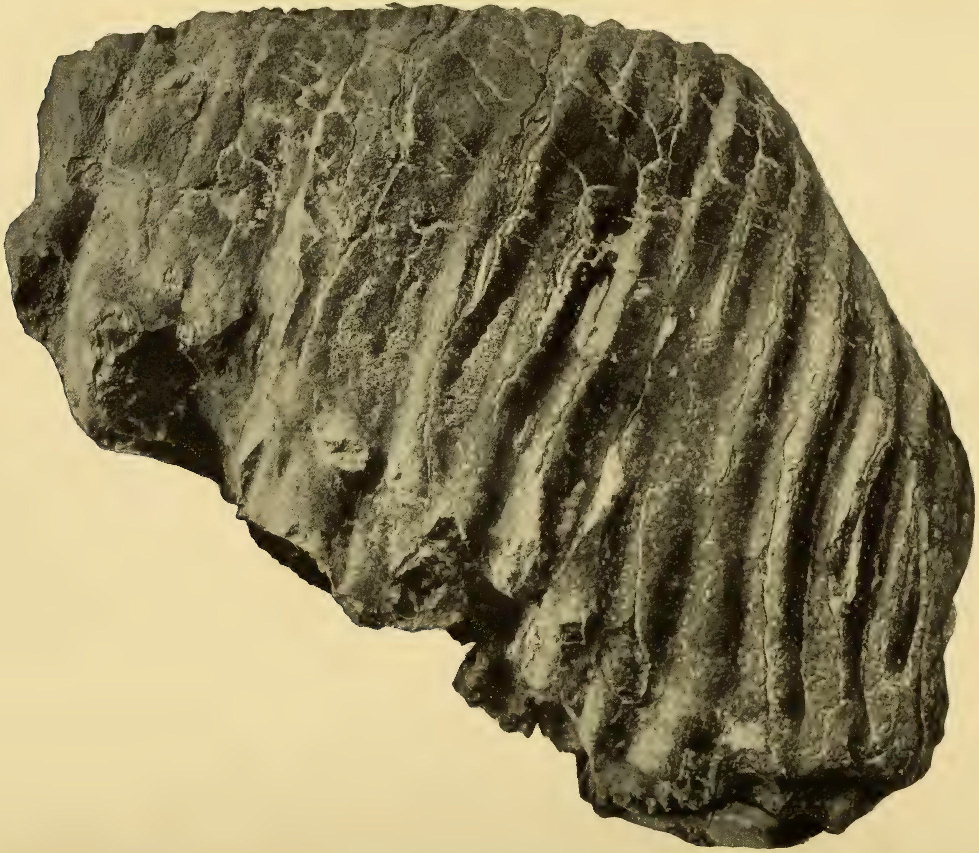
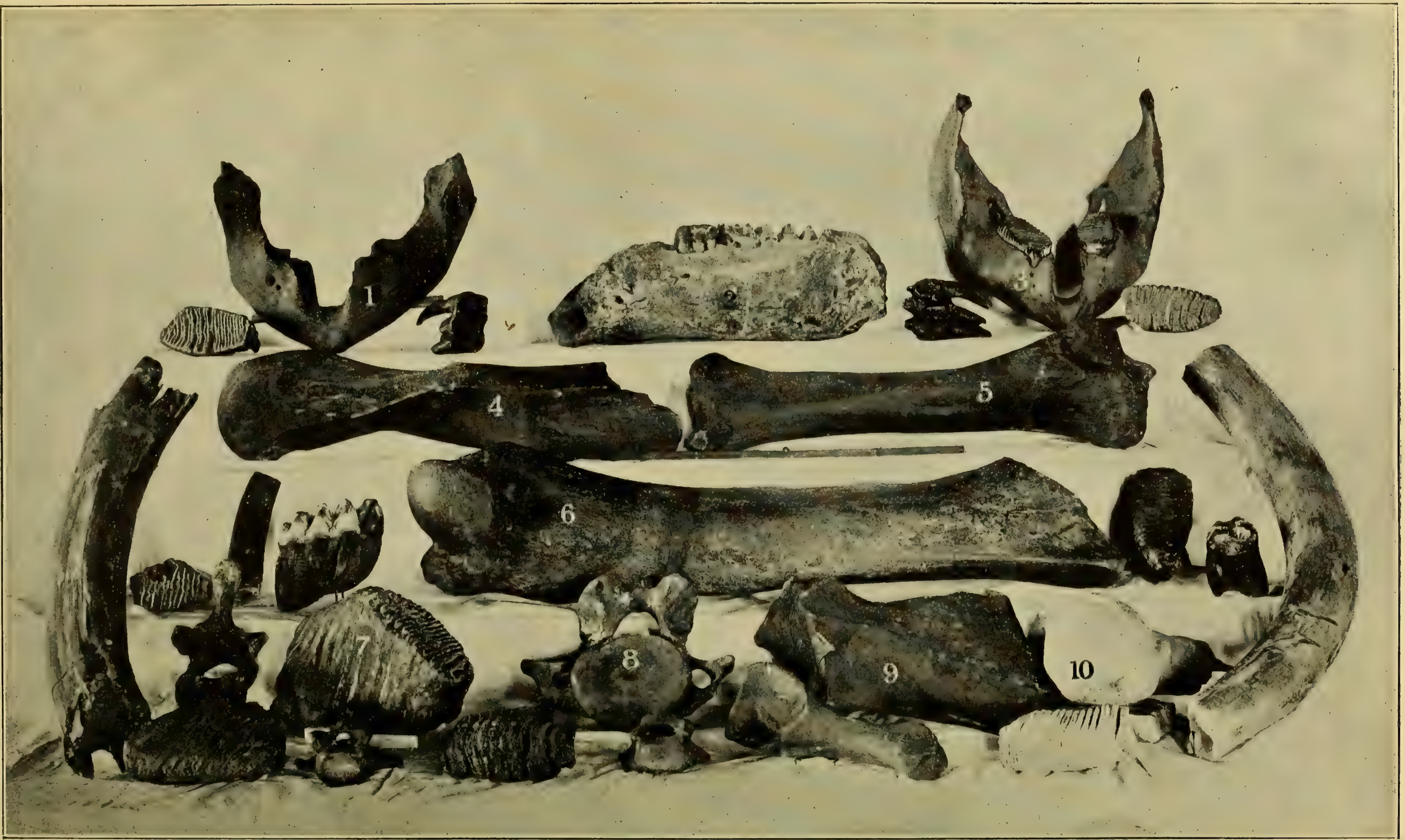
[12] The length of the femur of the Warren mastodon does not seem to be stated in Doctor Warren's classic memoir, but on page 107 he compares the femur of the Cambridge mastodon with that of the elephant Pizarro. This bone in the Cambridge specimen measures only 36 inches in length. In the Twenty-first Annual Report of the Regents of the University of the State of New York, pages 120 and 127, there are comparative measurements; the femur of the Warren mastodon is given as 45 inches long and that of the Cohoes mastodon as 41½ inches.



MOLAR OF ELEPHAS IMPERATOR

Side view of molar of *Elephas imperator* Leidy, Peyton pit. Three-sevenths natural size



FOSSIL BONES FROM AFTONIAN GRAVELS

Figure 1. Imperfect lower jaw of *Elephas imperator*, from Cox pit. Figure 2. Left ramus of Mastodon from the Peyton pit, Pisgah, Iowa. Figure 3. Lower jaw, lacking proximal articulations, of *Elephas columbi* Falconer, from alluvial deposits near Marengo, Iowa; horizon uncertain. Figure 4. Imperfect humerus from Peyton pit, Pisgah. Figure 5. Perfect left tibia from Cox pit, Missouri Valley. Figure 6. Imperfect femur from Peyton pit, Pisgah. The fragment measures 45 inches in length; probably represents *Elephas imperator*. Figure 7. Molar of *Elephas imperator*, from Peyton pit, Pisgah. Figure 8. Cervical vertebra from an Aftonian gravel pit at Turin, Iowa. The fragments of tusks are from the gravel pit at Denison, and the separate Mastodon teeth are from the Cox pit at Missouri Valley. All figures are greatly reduced.

ference from its great size that it belonged to the imperial mammoth, a tooth of which (plate 24) comes from the same gravel pit.

EDENTATA

MEGALONYX

Some years ago Todd called attention to beds of sand and gravel below drift in southwestern Iowa. A paper on the subject was read before the American Association in 1889,[13] and the abstract states that "a large claw of some gigantic mammal was shown, which was obtained from Mills county, Iowa, in the sand below the drift." A footnote referring to the specimen says that "this has been determined by Professor Leidy to be a claw of a Megalonyx." The "sand below the drift" in Mills, as in all the other counties of western Iowa, is interglacial. It lies below the Kansan drift, but there is another sheet of drift, the pre-Kansan, below it. On the basis of Leidy's determination, however, the Megalonyx may be accepted as a part of the Aftonian mammalian fauna.

MYLODON

From the noted Cox pit at Missouri Valley there comes an imperfect terminal phalanx of Mylodon (plate 26). The tip of the ungual process is broken off; otherwise it is practically complete and shows the characteristics of this part of Mylodon very clearly. The claw as a whole is proportionately much thicker, is less falcate, and tapers less rapidly toward the point than do the claws of Megalonyx. The ungual process is regularly rounded on the upper side instead of being compressed to a relatively sharp ridge. All the characteristics coincide with Owen's classical description of the distal phalanges of Mylodon.[14]

CORRELATION

The Aftonian fauna is as yet very incomplete. Additions to the list of species must wait on the further development of the sand pits and gravel beds. Besides the sloths, the forms thus far discovered and recognized are all large herbivores. An attempt to correlate the Aftonian beds with Pleistocene faunal zones which have been established in regions lying outside the glaciated area would probably, at the present time, be somewhat premature, but there are a few facts of some significance which may be noted. The deposition of the pre-Kansan drift certainly did not take place until some time after the actual beginning of the Pleistocene, and yet *Elephas imperator* was present in the long, mild interval which followed the pre-Kansan. Associated with the imperial mammoth were such typical members of the Equus fauna as *Equus scotti* and *Equus complicatus.* The camel and the Mylodon add other faunal elements which have some bearing on the question of correlation. Fragmentary and incomplete as is our knowledge of the Aftonian fauna, enough is known to warrant the statement that it resembles most closely the fauna of the Equus zone or "Sheridan formation" as that fauna has been listed by Matthew[15] and Osborne.[16] The localities from which the Aftonian fossils have been collected are not very far from the type localities of the Sheridan beds in Sheridan county, Nebraska. A statement by Scott, remarkable for its insight and suggestiveness, may here be quoted. Speaking of the Sheridan stage (*Equus beds*), he says:[17]

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[13] J. E. Todd: Evidence that lake Cheyenne continued till the Ice age. Proceedings of the American Association for the Advancement of Science, vol. xxxvii, 1889, pp. 202-293.

[14] Richard Owen: Description of the skeleton of an extinct gigantic sloth. *Mylodon robustus* Owen, pp. 94, 95, 107, 122. Leidy's work, A memoir on the extinct sloth tribe of North America. Smithsonian Contributions to Knowledge, accepted for publication December, 1853, p. 37, describes the ungual phalanges of Megalonyx. The plates in both of these publications assist in making clear the differences between the claws of the two great sloths mentioned.

> "It is, to a large extent, of æolian origin and in places contains great numbers of fossil bones. In South Dakota the Sheridan passes under a drift sheet, and probably it corresponds to one of the earlier interglacial stages."

If, as now seems probable, the Sheridan may be correlated with the Aftonian, it corresponds to the very earliest of the known interglacial stages. Though it follows an interval of rather rigorous and widely distributed glacial conditions, the Aftonian must still be reckoned as part of the Lower, or earlier, Pleistocene; for it is very old when compared with the Yarmouth, the Sangamon, and the subsequent interglacial intervals. To the deposits of these later stages we must look for remains of the faunas of the Middle and Upper Pleistocene, if representatives of these faunas are ever found in the glaciated areas.

POSTSCRIPT

As an illustration of the fact that, owing to the rapid growth of geological science, it is almost impossible to get a geological paper off the press before it is out of date, it may be said that since this paper was in the hands of the printer a considerable amount of new material has been

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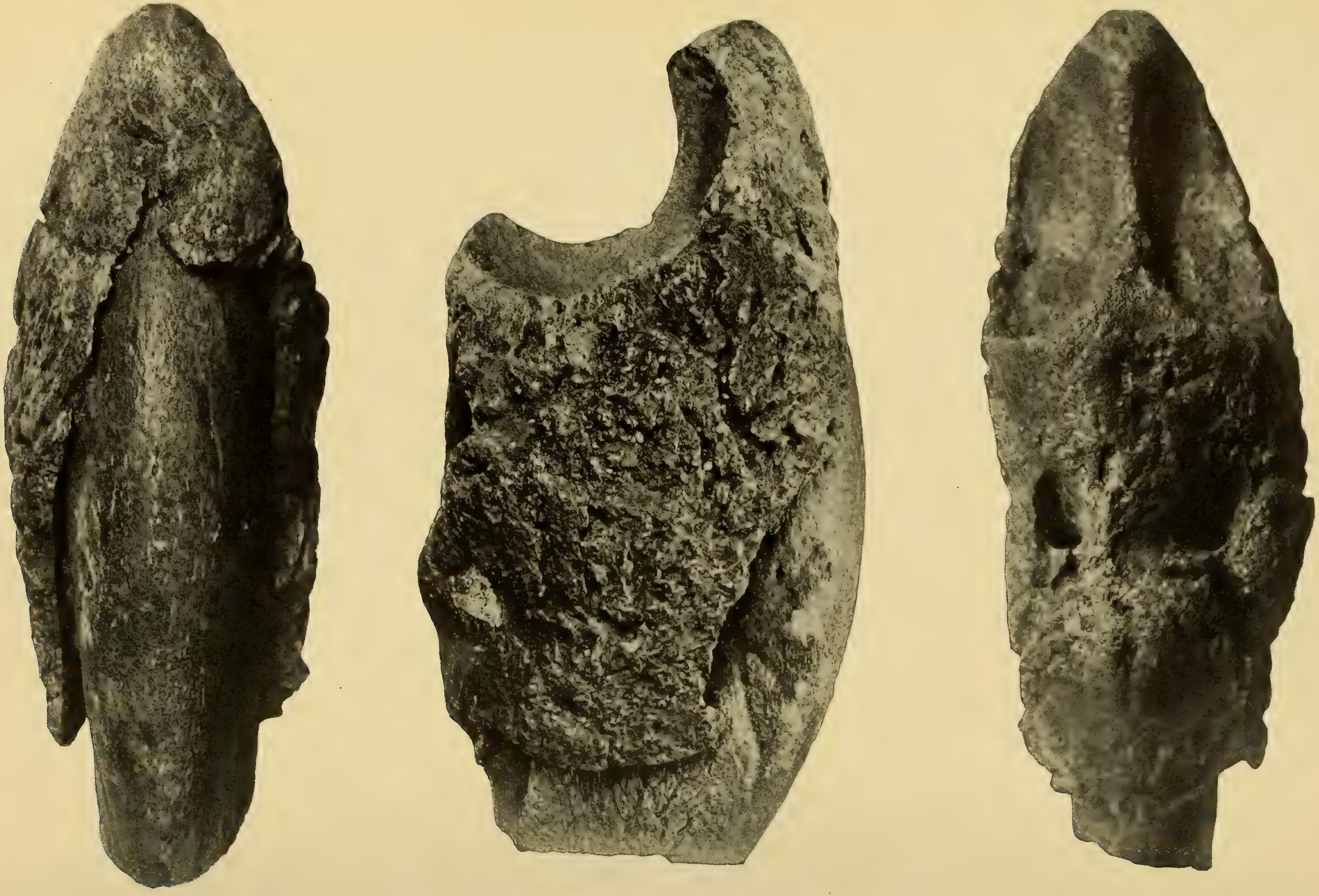
[15] W. D. Matthew: List of the Pleistocene fauna from Hay Springs, Nebraska. Bulletin of the American Museum of Natural History, vol. xvi, p. 317.

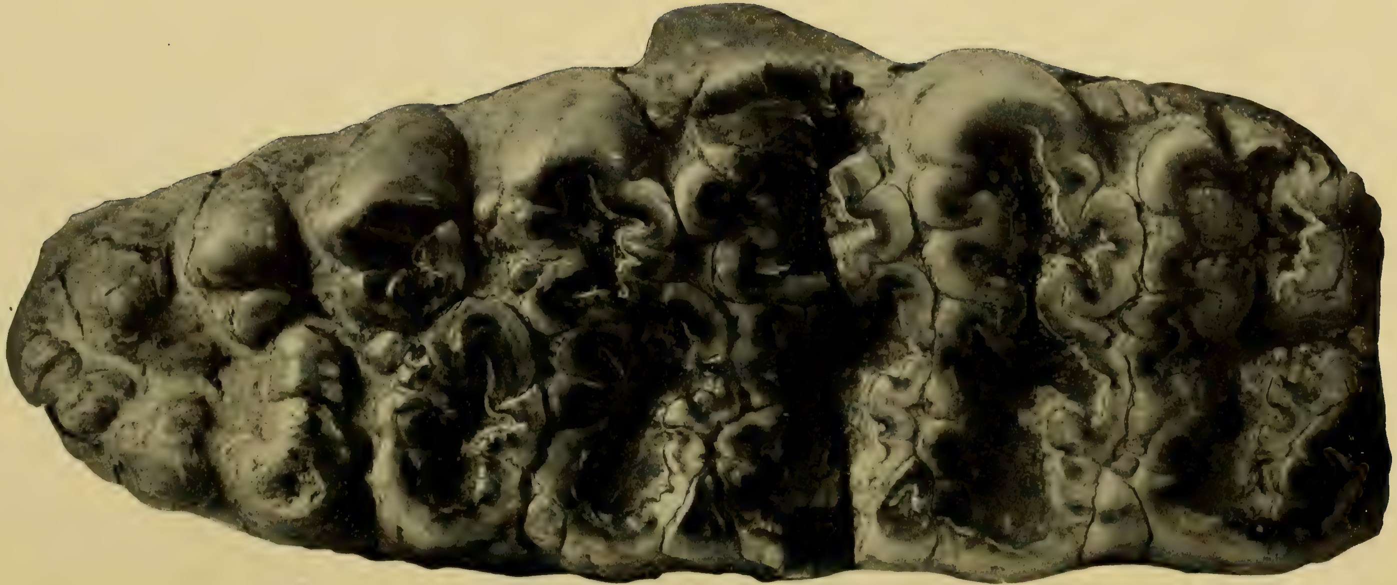
[16] Henry Fairfield Osborne: Cenozoic Mammal Horizons of Western North America. Bulletin no. 361, U. S. Geological Survey, p. 85.

[17] William B. Scott: An Introduction to Geology, second edition, p. 782. New York, 1908.



SUPERIOR, LATERAL, AND INFERIOR VIEWS OF CLAW OF MYLODON

From the Cox pit at Missouri Valley. Natural size



MOLAR OF MAMMUT MIRIFICUM LEIDY

Grinding surface of the last superior right molar of *Mammut mirificum* Leidy, from Aftonian gravel penetrated in digging a well near Akron, Iowa
About five-sixths natural size

received from the Aftonian gravels of southwestern Iowa. There are superior and inferior molars of *Equus complicatus* and a fine claw of *Megalonyx* from gravel pits at Sioux City. From Missouri Valley there are a sixth molar of mastodon, a superior grinder of *Equus scotti,* and a second inferior molar of *Camelus.* A pit at Logan has furnished a fine molar of *Elephas columbi,* while from Turin there has been received a large collection which includes a sixth molar of mastodon, three metatarsals and three first phalanges of *Equus,* two phalanges of *Camelus,* a phalanx of either elephant or mastodon, and a great number of imperfect bones not yet identified.

The probable presence of *Megalonyx* as a member of the Aftonian fauna is noted in the body of the paper; the only point concerning which there might be possible doubt is the age of the beds in which the specimen collected by Todd was found; the claw now in hand from Sioux City places the matter of an Aftonian *Megalonyx* beyond question.

We now have remains of Aftonian camels from three localities—Turin, Pisgah, and Missouri Valley.

Two of the equine metatarsals and two of the phalanges from Turin are decidedly larger than the corresponding bones from the modern horse. One of these large cannon bones is complete and measures 30.5 centimeters in length, while a metatarsal of a fair sized modern horse, with which it is compared, measures but 27 centimeters. Other measurements show corresponding differences between the fossil and the domestic species. One of the teeth noted in the paper (figures 2, 4, plate 18) agrees in size with *Equus pacificus* Leidy. It is larger than the teeth of *Equus scotti* recorded by Gidley. It may be possible that this large tooth and these large cannon bones belong to a species larger than *Equus scotti;* but on the other hand it is possible that individuals varied, and that some of the animals belonging to the species *Equus scotti* may have exceeded "the size of the largest western pony." The solution of some of these questions must await additional evidence.

Probably the most important of the recent additions to our knowledge of the Aftonian mammals comes in the form of two molars of *Mammut mirificum,* or *Mastodon mirificus* Leidy. These teeth were found in Aftonian gravel which was penetrated in digging a farm well near Akron, in Plymouth county, Iowa. They are well worn down by use, and show the characteristic features of this remarkable species unusually well (plate 27). The teeth are the last of the upper molar series—one right, one left. With them were found portions of the tusks and a large number of pieces of the cavernous cranial bones. A part of the maxillary still adheres to the left molar. The left tooth measures 8¾ inches long and 3¼ inches wide across the second ridge. The right tooth is slightly smaller, 8½ inches long, and the corresponding widths are also somewhat less.

Leidy described the last lower molars of this species,[18] and he found a somewhat similar disproportion between the right and the left. As in the teeth described by Leidy, the main body of the Akron molars is made up of six divisions or ridges. The sixth division, however, is somewhat irregular, and in the right molar is made up of more than two lobes. Behind the sixth ridge are elements of rudimentary ridges in the shape of a number of mammiform tubercles, not shown in the specimen illustrated by Leidy on plate xxv, figure 2, of the work cited. The wearing down of the lobes of the transverse ridges exposes "large tracts of dentine bordered by thick festooned bands of enamel." Our teeth are worn more than the lower teeth described by Leidy, and in the third division, as well as in the first and second, the dentinal tract is continuous. In the fourth and fifth ridges the tracts are still separated by the thick enamel.

The beds on the Loup river, from which the original specimens of *Mastodon mirificus* came, have been variously correlated with the Miocene, the middle and later Pliocene, and the early Pleistocene. Osborn in U. S. Geological Survey Bulletin 361, page 84, includes *Mastodon mirificus* in the fauna of the *Elephas imperator* zone, but remarks later on the same page that "the exact position of the *Elephas imperator* zone, also the question of whether it is of the same age as the *Equus* zone, remain to be determined." It is now certain that typical representatives of the *Equus* fauna are associated with *Elephas imperator* and *Mastodon mirificus* in the Aftonian beds of western Iowa, and it is worthy of note that *Mastodon americanus* occurs abundantly in the same association. Significant among the new finds not heretofore recorded are a characteristic tooth of the imperial elephant and a tusk and sixth molar of the American mastodon, which were taken from gravels under Kansan drift, in wells near Mapleton.

Mastodon mirificus Leidy may be compared with Cope's *Dibelodon humboldtii* Cuvier, referred to in the Fourth Annual Report of the Geological Survey of Texas. Cope regards the horizon from which his specimens came as "more or less exactly equivalent to the *Equus* beds."

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[18] Leidy: The extinct mammalian fauna of Dakota and Nebraska, Philadelphia, 1869, p. 249, pl. xxv, figs. 1, 2.

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UNCONFORMITY IN THE SO-CALLED LARAMIE OF THE RATON COAL FIELD, NEW MEXICO[1]

BY WILLIS T. LEE

(*Read before the Society December 29, 1908*)

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PRELIMINARY STATEMENT OF RESULTS

The purpose of this paper is to describe an unconformity hitherto unknown that is of more than ordinary interest because it divides rocks, previously referred to the Laramie, into two distinct formations. The investigation is not complete, but enough is known to warrant the statement that during the time interval represented by the unconformity the sedimentary rocks previously laid down within the Raton field were subjected to erosion for a considerable length of time and the Rocky mountains west of this field were elevated and eroded to a depth of several thousand feet.

The positions in the geologic column of the two coal-bearing formations are not yet fully determined. Until they are studied in detail and final correlations made, the positions here assigned and the names used should be regarded as serving only the temporary purpose of giving definiteness to the description. The upper formation has the stratigraphic position of the Arapahoe of the Denver basin, but contains a flora apparently more closely related to that of the Denver formation than it is to the Laramie of the Denver basin. The lower one has the stratigraphic position of the Laramie of the Denver basin, but contains a flora that is apparently older than Laramie. There are several possibilities of interpretation, as will be pointed out in the following pages, but the one considered most probable is that the uplift and erosion represented by the unconformity is contemporaneous with the post-Laramie uplift and erosion described by Cross[2] and others from the Denver region.

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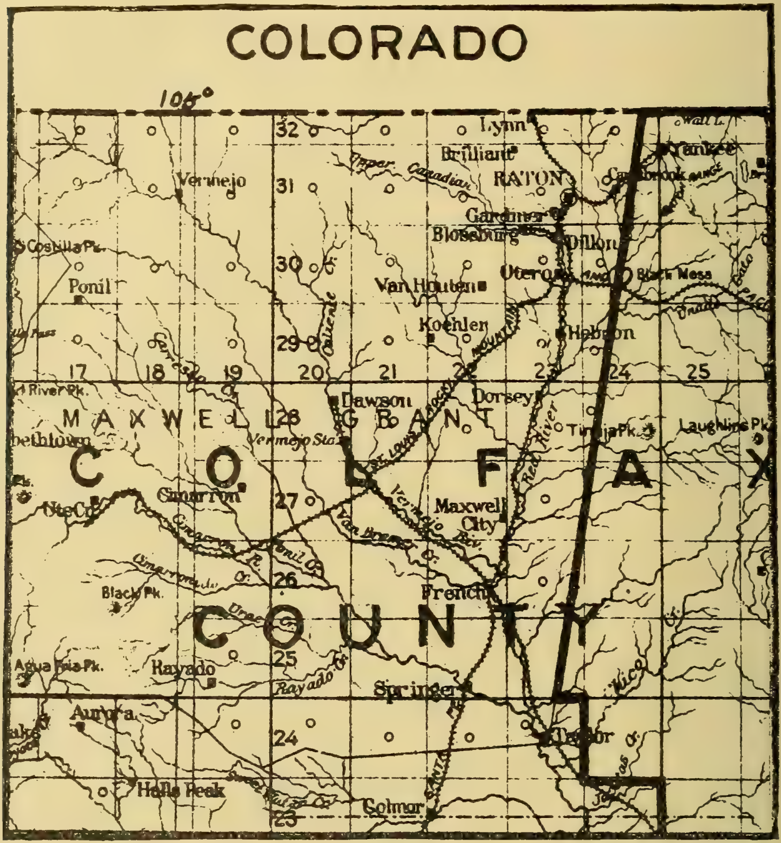
[1] Published by permission of the Director of the U. S. Geological Survey. Manuscript received by the Secretary of the Society September 15, 1909.


COLORADO
105°
Lynn
Brilliant
RATON
Upper Canadian
Gardiner
Blossburg
Dillon
Otero
Black Mesa
Vermejo
Costilla Pk.
Ponil
Van Houten
Koehler
Hebron
Dawson
Dorsey
MAXWELL GRANT
COLFAX COUNTY
Vermejo Sta.
Cimarron
Ute Cr.
Maxwell City
Laughlin Pk.
Tinaja Pk.
Red River
Vermejo Riv.
Van Bremer Cr.
Cimarron R.
Ponil Cr.
French
Black Pk.
Agua Fria Pk.
Rayado
Rayado Cr.
Springer
Taylor
Aurora
Hells Peak
Colmar
Yankee
Wall L.
River Pk.
17
18
19
20
21
22
23
24
25
28
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31
30
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FIGURE 1.—*Key Map of Part of Northern New Mexico, including Raton Coal Field.*

(From map of the General Land Office.)

LOCATION AND CONDITION OF THE ROCKS DESCRIBED

The area described is in northern New Mexico east of the Rocky mountains and constitutes the southern part of the Raton mesa region, the northern, or Colorado, part of which is well known through the writings of Hills.[3] The Raton field extends from the Colorado line southward beyond the Cimarron river, a distance of about 40 miles, and from the base of the Rocky mountains eastward about 50 miles. Near Raton the rocks outcrop in the steep slopes of the lava-capped mesas that are frequently, though erroneously, called the Raton mountains. To the south and west of Raton the rocks have been deeply eroded and good exposures are numerous; also in the western part of the field the rocks are well exposed where they are upturned in Vermejo park and along the base of the Rocky mountains for a distance of about 5 miles south of the Colorado line. Farther south the outcrop is obscured by slide rock and the relations complicated by intrusions of igneous rock. From Ute park eastward in the Cimarron canyon and northward along the southeastern margin of the coal field many well exposed sections of the rocks were measured. Illustrations of these exposures are given in plate 30.

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[2] Whitman Cross: Geology of the Denver basin in Colorado. U. S. Geological Survey Monograph no. 27, 1896.

Rock Formations

Although little can be said of the older rock formations of the Raton region, some knowledge of their general character and thickness is necessary in order to appreciate certain facts relating to the unconformity here described.

The oldest formations of the region consist of the ancient crystalline and metamorphic rocks, probably of pre-Cambrian age. These are overlain in some places by sediments of Pennsylvanian age and in other places by the red beds of the eastern Rocky mountains that probably range from late Pennsylvanian to Triassic. The red beds are here coarsely conglomeratic, containing boulders of crystalline and metamorphic rocks derived from the older complex, and are so faulted and otherwise disturbed that it is difficult to measure their thickness, but 10,000 feet is believed to be a conservative estimate.

The red beds are overlain by about 300 feet of Morrison shale and 200 or more feet of Dakota sandstone. Above the Dakota is a thickness of 3,000 feet or more of marine Cretaceous shale, the upper part of which is referred on paleontologic evidence to the Pierre. This shale grades upward through a transition zone of sandy shale, which Hills calls lower Trinidad,[4] to the massive Trinidad sandstone, which varies from 50 to 120 feet in thickness and which contains a marine fauna allied to that of the Pierre shale, but which in some places contains also thin beds of coal and plant remains similar to those in the overlying coal measures. The coal-bearing rocks above the Trinidad sandstone are those that heretofore have been called Laramie, but that are now known to constitute two formations. Since final correlations have not been made, it seems inadvisable to use definite names for these formations; but, as shown later in this paper, there are reasons for believing that the lower one may prove to be older than Laramie and the upper one younger than Laramie. For this reason the coal-bearing rocks above the unconformity will be provisionally referred to as the post-Laramie coal measures and those below it as the Cretaceous (Laramie or older) coal measures.

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[3] R. C. Hills: U. S. Geological Survey, Elmoro folio, no. 58, 1899; also U. S. Geological Survey, Spanish Peaks folio, no. 71, 1901.

[4] R. C. Hills: U. S. Geological Survey, Elmoro folio, no. 58, 1899.

Rock Formations in the Raton Field.

Cretaceous.		Sandstone, conglomeratic, lithologically similar to the Poison Canyon beds, and provisionally correlated with the Denver formation.
	* Post-Laramie (?) 1,200 feet.	Sandstone below, conglomeratic at the base; coal-bearing shale above.
	Unconformity.	
	* Laramie or older (?) 0–475 feet.	Shale and sandstone, coal-bearing.
	Trinidad, 50–120 feet.	Sandstone, shaly at base.
	Pierre, Niobrara, and Benton, 3,000 + feet.	Shale.
	Dakota, 200 ± feet.	Sandstone.
(?)	Morrison, 300 ± feet.	Shale and sandstone.
Pre-Cretaceous.	Red beds, 10,000 ± feet.	Red sandstone, coarsely conglomeratic, containing boulders of the underlying crystalline and metamorphic rocks.
	Pennsylvanian (?)	Sandstone, shale, and limestone.
	Archean.	Ancient igneous and metamorphic rocks.

The Cretaceous coal measures consist of shales and sandstones having a maximum measured thickness in Vermejo park of 475 feet, and lie apparently with perfect conformity on the Trinidad sandstone. They thin rapidly eastward, their maximum thickness in the eastern part of the field being only 114 feet, while in some places not only were they completely eroded away, but the underlying Trinidad sandstone also was deeply eroded. The post-Laramie formation has a maximum measured thickness of 1,200 feet. The lower half consists principally of sandstone that is commonly conglomeratic at the base. The upper half has a greater proportion of shale, but in some places near the top there are thick beds of conglomerate, apparently belonging to a younger formation, the Poison canyon, but not separated from the underlying beds by any sharp line of demarkation.

---

* Formerly called Laramie.

Evidence of Unconformity

In order to appreciate the significance of some of the facts relating to the unconformity here described, it is necessary to consider certain conditions existing previous to the uplift and erosion that produced it.

(*a*) The absence of arenaceous material from the marine Cretaceous shale in the Raton field warrants the inference that the land areas which furnished the sediments either were located at great distances from this field or were so nearly baseleveled that the streams draining them could transport only clay and fine silt, and apparently proves fallacious any postulate that would account for the conglomerate at the base of the post-Laramie formation without renewed uplift in the mountain region from which the conglomerate was derived and the removal from the uplifted portions of considerable thicknesses of sediment.

(*b*) The change in the character of the sediments from the fine textured shale of the Pierre to the coarse sand of the Trinidad sandstone may be due to uplift in neighboring areas, but this postulate is not necessary to account for the presence of the sand, for this sandstone represents the last stage of the vanishing Cretaceous sea and the sand may have been transported along shore from great distances.

(*c*) The Cretaceous coal measures lie conformably on the Trinidad sandstone and were probably accumulated on broad, low-lying flats that were subject to slight oscillations. There are no fragments in them larger than grains of sand and the bedding is comparatively regular, differing notably in this respect from the post-Laramie beds, which are lenticular in many places. Few organic remains were found that would indicate the conditions under which the sediments were laid down. In one locality the supposed seaweed, *Halymenites major*, was found in rocks above the lowest coal bed, but fossil leaves indicative of fresh-water conditions were found in several other places. Judging from the regularity in the bedding of the sediments, no great difference in the *original* thickness of the Cretaceous coal measures would be expected, yet the observed difference is 475 feet, the entire formation disappearing within a distance of 15 miles from the point of its maximum thickness.

The contact between the Cretaceous coal measures and the conglomerate at the base of the post-Laramie is traceable in the face of the cliffs as an unmistakable line of unconformity by erosion. Near the Van Houten mine the conglomerate rests on 13 feet of coal and in a number of places within the mine conglomeratic material fills irregular cavities in the coal bed. Apparently these masses are due to the filling from above of fissures and irregular openings formed at about the time the conglomerate was deposited. A quarter of a mile south of Van Houten this coal bed and 40 feet of underlying sandstone and shale are absent and the conglomerate rests on the Trinidad sandstone; also differences in the degree of dip between the Cretaceous and the post-Laramie coal measures were noted in a few places where for short distances the conglomerate extends across the eroded edges of the older beds, as shown in figure A, plate 28.

The following is a description of the sections represented on plate 28:

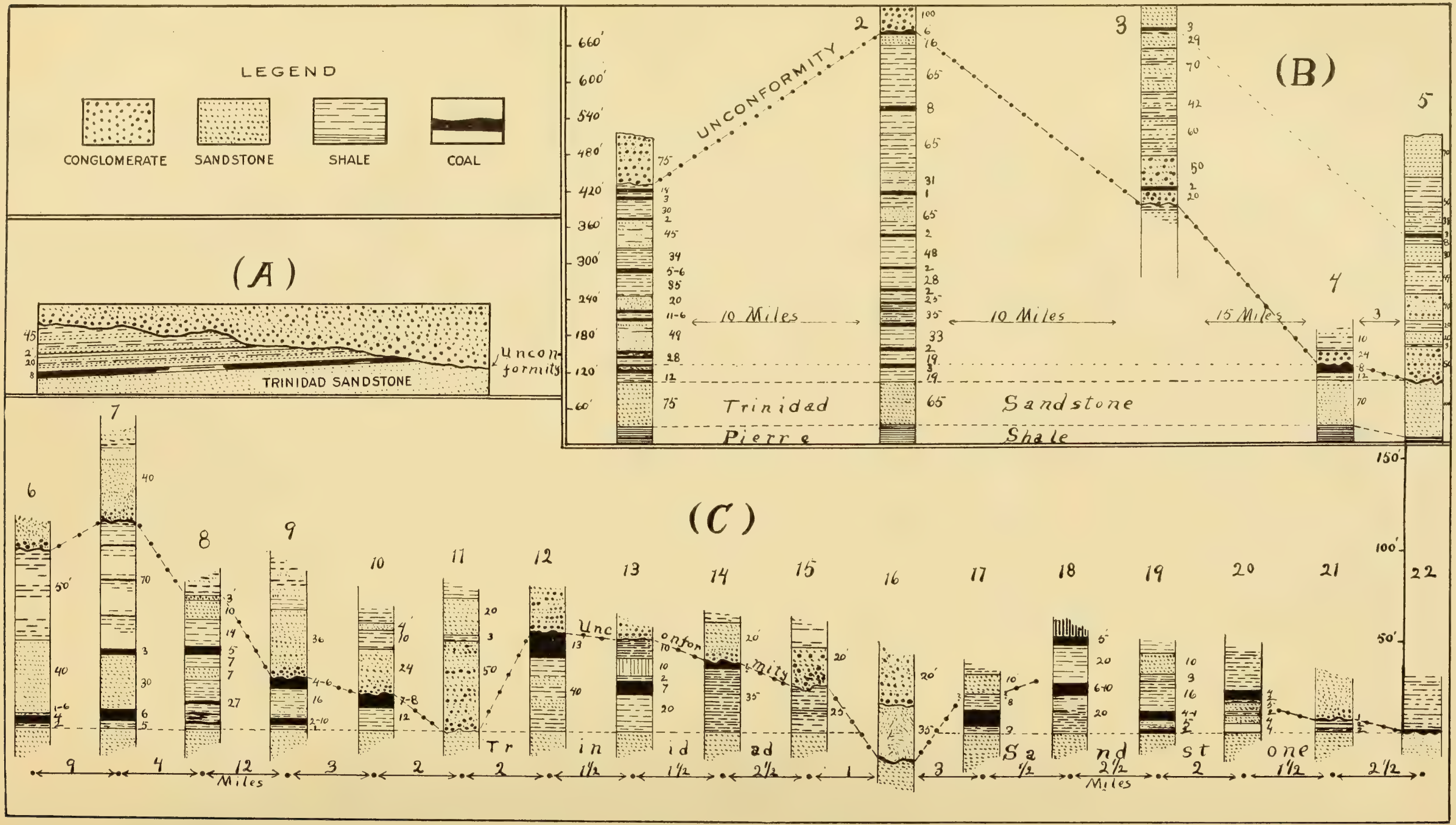
A is a section of Cottonwood canyon near Red River peak. The bedding planes of the lower formation dip 3 degrees; those of the upper are horizontal.

B is a series of columnar sections extending from the base of the Rocky mountains eastward to Van Houten.

(1) Section in hogback 5 miles south of the Colorado-New Mexico boundary.
(2) Section near the southeastern extremity of Vermejo park.
(3) Section in Vermejo canyon east of Vermejo park.
(4 and 5) Sections at eastern margin of field south of Van Houten.

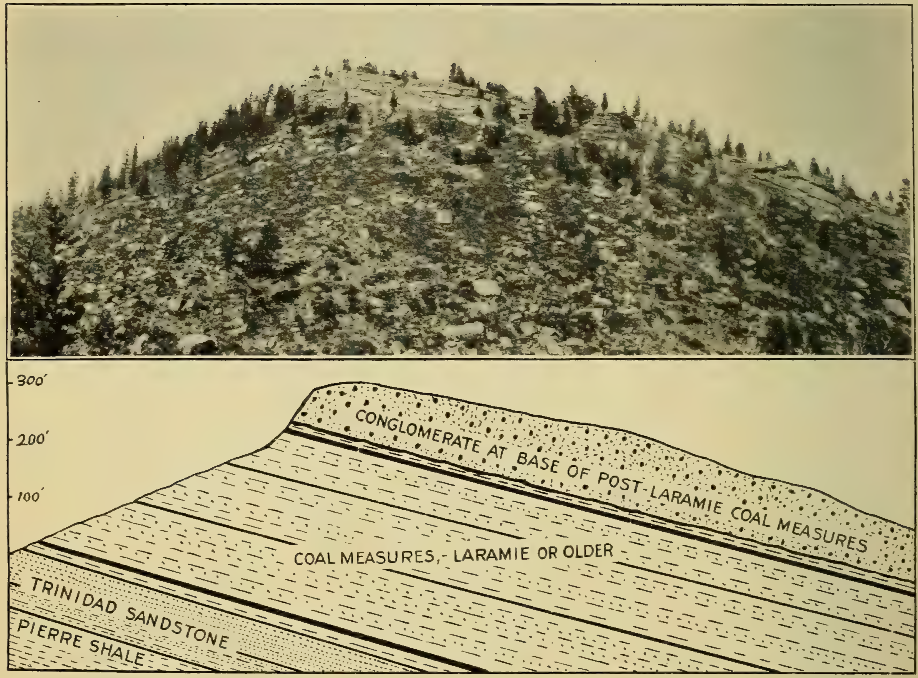
C represents a series of columnar sections from near Carresso creek (6) northward along the eastern margin of the field.

(6) Cliff south of Carresso creek.
(7) Dawson, west side of Vermejo canyon.
(8) Four miles east of Dawson.
(9) Half mile north of Koehler.
(10) Three miles east of Koehler.
(11) Two miles southeast of Van Houten.
(12) Van Houten mine.
(13) North fork of Willow creek, 1½ miles north of Van Houten.
(14) Two and a half miles west of Red River peak.
(15) Red River peak.
(16) One mile north of Red River peak.
(17) North wall of Red River canyon.
(18) Half mile south of Gardner.
(19) One mile south of Raton.
(20) Mesa north of Raton.
(21) One and a half miles northeast of Raton.
(22) Southeastern point of Bartlett mesa, 4 miles east of Raton.


LEGEND
CONGLOMERATE
SANDSTONE
SHALE
COAL
(A)
TRINIDAD SANDSTONE
Unconformity
(B)
UNCONFORMITY
2
3
4
5
660′
600′
540′
480′
420′
360′
300′
240′
180′
120′
60′
10 Miles
10 Miles
15 Miles
3
Trinidad Sandstone
Pierre Shale
(C)
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
Unconformity
Trinidad Sandstone
150′
100′
50′
9
4
12 Miles
3
2
2
1½
1½
2½
1
3
½
2½ Miles
2
1½
2½

SECTIONS OF COAL FORMATIONS OF THE RATON FIELD, NEW MEXICO

Showing character and relations of the unconformity separating the coal formations


300′
200′
100′
CONGLOMERATE AT BASE OF POST-LARAMIE COAL MEASURES
COAL MEASURES,-LARAMIE OR OLDER
TRINIDAD SANDSTONE
PIERRE SHALE

HOGBACK IN VERMEJO CANYON, NEW MEXICO

Formed by basal conglomerate of the post-Laramie coal measures

Sections were measured at short intervals in the escarpment along the eastern margin of the field, and these have been plotted to scale in figure C, plate 28, in order to show the irregularities in the line of unconformity. In figure B of the same plate measured sections are arranged in order from west to east, showing the thinning of the Cretaceous coal measures away from the mountains. The difference in thickness may be due in some measure to original deposition, but more probably is due to the partial removal by erosion of the Cretaceous beds. These facts apparently force the conclusion that no highlands existed near the Raton field which could by any known process, except that of invigorated erosion due to mountain uplift, furnish the pebbles found in the conglomerate at the base of the post-Laramie formation. There can be no reasonable doubt that erosion preceded the formation of the conglomerate, and the thinning of the Cretaceous coal measures from west eastward is best explained as due to this erosion. However, the most convincing proof of the duration of the erosion interval is found in the composition of the conglomerate.

CONGLOMERATE

The base of the post-Laramie formation in nearly all parts of the Raton field is conglomeratic. In the western part, where the formations are upturned along the base of the mountains, and in Vermejo park, the conglomerate is coarse, massive, and resistant and forms a prominent hogback (see plate 29). It is coarsest at the base, where through a thickness of 100 feet the pebbles attain a maximum diameter of five inches. Above this massive basal part there is a small amount of carbonaceous shale with thin seams of coal, but for 600 feet above the unconformity the sediments are principally coarse grained sandstones locally conglomeratic.

Eastward, or away from the mountains, the basal portion of the conglomerate thins and the pebbles are smaller. In the eastern part of the field the conglomerate is well developed as far north as Red river. Near Raton it is doubtfully represented by a quartzose sandstone, but still farther toward the east the conglomeratic character reappears, as is shown graphically in figure B, plate 28; also the upper part of the conglomerate, as represented in the foothills at the eastern edge of the field, becomes finer textured toward the east, loses its conglomeratic character, and apparently is represented in the eastern part of the field by the cliff-making sandstones that occur in the lower 400 feet of the formation east of Raton.

In the conglomerate were found pebbles of coal; sandstone similar to the Trinidad; quartzose sandstone similar to the Dakota; pebbles of conglomerate similar to the conglomerates of the Dakota; well rounded pebbles of petrified wood that may have been derived either from the Dakota or from the Cretaceous coal measures; red sandstone that could have come only from the red beds; cherty limestone with impressions of crinoid stems; a variety of cherts; quartz; quartzite; jasper; igneous rocks, some of which are coarsely crystalline, others fine-textured, such as are found in the dikes of the mountain region; and fragments of feldspar, most of them completely kaolinized, but some of them retaining their original form perfectly enough to show cleavage faces. The significance of these pebbles in showing the amount of erosion is made evident by reference to the thicknesses of the underlying strata shown in the generalized section previously given.

Measure of Erosion

An estimate of the amount of uplift and erosion represented by the unconformity involves the difficult problem of the distribution of land and sea and the altitude of the Rocky Mountain region during Cretaceous time. The assumption that a land-mass of crystalline rocks persisted in the mountain region throughout the Cretaceous period might satisfactorily account for the conglomerate without renewed uplift, were it not for the thick underlying bed of fine textured Cretaceous shale; but it is difficult to understand how a coarse conglomerate could be derived from a land-mass that had furnished no coarse material during the accumulation of marine shale more than 3,000 feet thick, until that land was reelevated. If it be conceded that the Rocky Mountain region of New Mexico was lowlying or submerged during the greater part of the Cretaceous period, and that uplift and renewed erosion preceded the deposition of the post-Laramie conglomerate, it remains to inquire what thickness of sediment was removed in order to expose to erosion the rocks represented by the various pebbles.

Again, it must be confessed that further investigation is necessary before definite figures can be given, for it is not known how far the formations now upturned in the foothills region originally extended westward over the present mountain area, nor have the thicknesses of the older sedimentary rocks in the Raton field been measured. The Cretaceous shale near Raton is known from well borings to be something more than 3,000 feet thick, and it is apparently much thicker than this near the mountains. The Dakota sandstone is about 200 feet and the Morrison shale at least 300 feet thick. The Red beds are faulted and otherwise greatly disturbed in this region, and their thickness can only be estimated at this time, but it is probably not less than 10,000 feet.

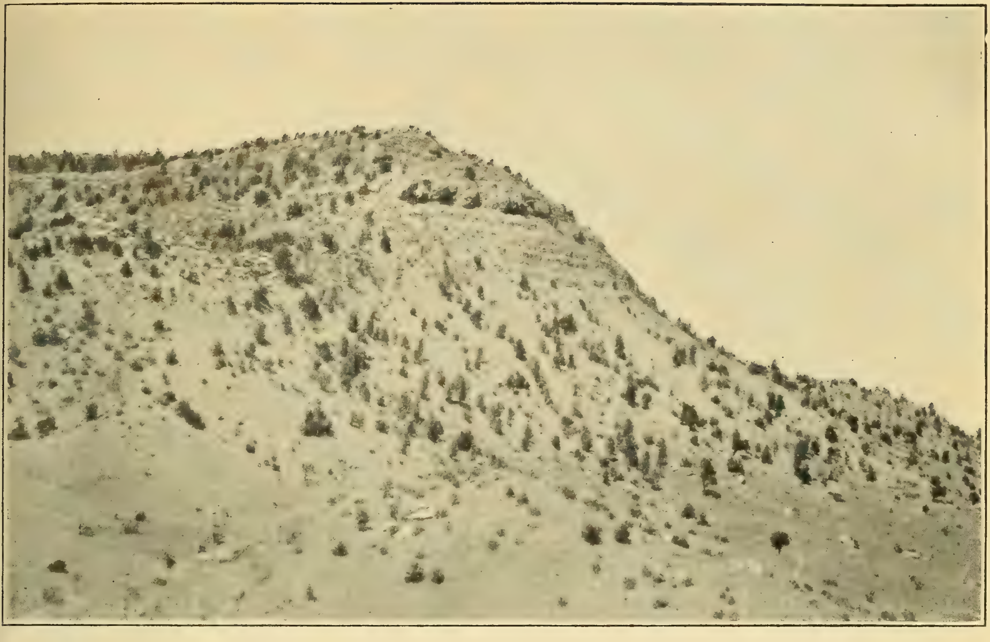


FIGURE 1.—CLIFF SOUTH OF CARRESSO CREEK, WHERE SECTION 6, PLATE 28, WAS MEASURED

The formations given in order from base upward are Pierre shale, Trinidad sandstone, Cretaceous coal measures, and post-Laramie conglomerate

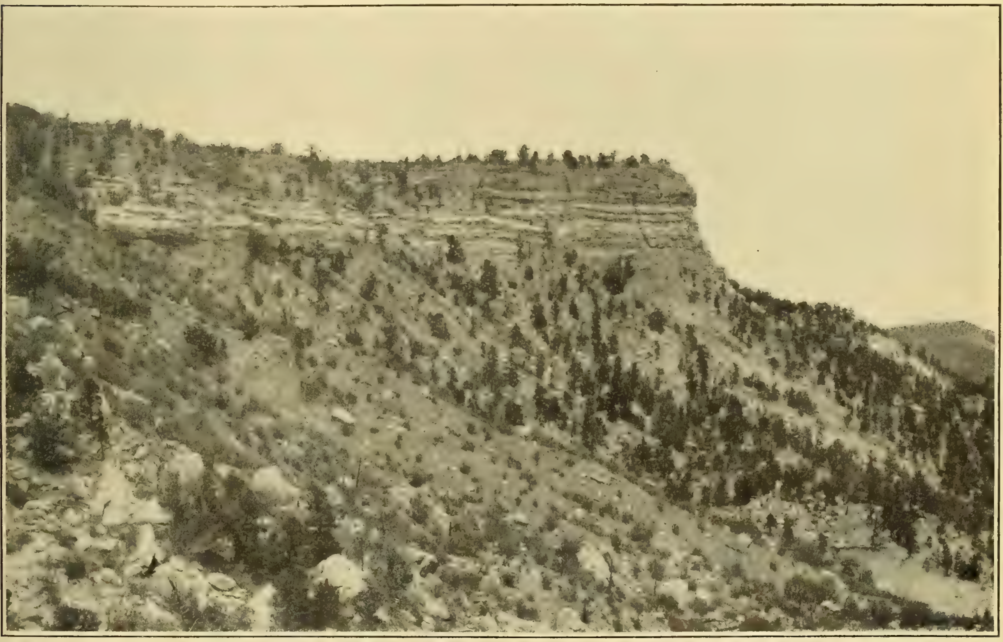


FIGURE 2.—CLIFF ONE MILE NORTH OF RED RIVER PEAK, WHERE SECTION 16, PLATE 28, WAS MEASURED

The post-Laramie conglomerate forming the top of the cliff rests unconformably on Trinidad sandstone

CLIFF NEAR CARRESSO CREEK AND CLIFF NORTH OF RED RIVER PEAK, NEW MEXICO

Assuming that the formations once continued westward with undiminished thickness over the region now occupied by the southern end of the Rocky mountains, there must have been differential uplift and the removal of at least 3,600 feet of sediment before the pebbles of Dakota sandstone were obtainable, and erosion of at least 4,100 feet before the red sandstone was reached. The pebbles of igneous and metamorphic rocks that constitute the principal part of the post-Laramie conglomerate may have come from the coarser portions of the Red beds. There were boulders enough in the Red beds to have supplied the pebbles of the post-Laramie conglomerate, but the granitic material in the Red beds is regarded as quantitatively inadequate to furnish the feldspar which forms a considerable part of this conglomerate. It is probable that the granite rocks underlying the Red beds were exposed to erosion and furnished the feldspars, in which case the differential uplift and subsequent erosion could have been scarcely less than 15,000 feet. This estimate will probably be modified after further investigation, but the statement is amply justified that the unconformity in the Raton field represents erosion comparable to the post-Laramie erosion of the Denver region, which Cross[5] places at 14,000 feet.

CORRELATIONS

In some places in the Raton field the Trinidad sandstone contains marine invertebrates which, according to T. W. Stanton, who has identified them, are of Montana age, belonging to the same fauna as that of the underlying Pierre shale. In other places it contains thin beds of coal and fossil leaves similar to those in the overlying coal-bearing rocks. Undoubtedly the Pierre shale, the Trinidad sandstone, and the coal beds below the unconformity represent practically continuous deposition. The stratigraphic succession is essentially the same as that in the Denver region, where the Laramie is the last of the conformable Cretaceous series and the marine beds contain invertebrates by which they are correlated with beds of similar position in the Denver section. However, the rocks of the Raton field that have the stratigraphic position of the Denver Laramie have yielded 15 species of plants, named in the accompanying table, which, according to F. H. Knowlton, who has identified them, are apparently older than Laramie. The species common to the Denver Laramie, as shown in the table, are those known to have a long time range and are therefore of little use for correlation. The flora is not a large one and is not adequate for final correlation of the beds.

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[5] **Whitman Cross: Age of the Arapahoe and Denver formations. U. S. Geological Survey Monograph no. 27, 1896, p. 207.**

The rocks above the unconformity have yielded a flora larger than that of the rocks below. From collections made by the writer in 1908, Knowlton identified the 29 forms listed in the following table. Of these 29 forms, 13 are positively identified species. Nine of the 13 occur in the post-Laramie of the Denver basin and only 2 in the Denver Laramie. Commenting on the age of this flora, Knowlton states that it is apparently post-Laramie and more closely related to the Denver than to the Arapahoe flora, which perhaps is to be accounted for by the fact that the known Arapahoe flora is very small as compared with the known Denver flora. This opinion is strengthened by the known range of the species previously found in the Raton Mesa region. The existence of the two coal-bearing formations has not been recognized heretofore, but judging from descriptions of localities from which the collections came, most if not all of the 62 species of plants formerly collected in this region, mainly by the geologists and paleontologists of the Hayden Survey, came from the post-Laramie beds. Knowlton states that 20 of the 62 species are found only in the Raton Mesa region and can not be used for correlation, but that 42 of them are found elsewhere. Of these 42 species 24 have been found in the post-Laramie formations (Arapahoe and Denver) of the Denver basin, but only 3 are known from the Denver Laramie, and these 3 range downward into the Montana.

In the absence of data sufficient for the definite correlation of the beds described, a choice of interpretation is left open in explanation of the observed stratigraphic relations. In case all of the coal-bearing rocks of the Raton field are referred to the Laramie, as they have been up to the present time, we are confronted with the fact that the "Laramie" in this field contains an unconformity of considerable magnitude. By accepted definition the name Laramie is "restricted to the rocks conformably overlying the uppermost marine Cretaceous (Lewis shale where present) . . . the upper limit to be the first marked unconformity or its stratigraphic equivalent." It is evident either that the definition is not applicable in the Raton field or that the coal-bearing rocks are not all of Laramie age. By definition the coal-bearing rocks in this field below the unconformity might be either Mesaverde or Laramie, but the rocks above the unconformity must be post-Laramie. If the lower formation be referred to the Laramie, the stratigraphic relations in the Raton field are apparently identical with those in the Denver basin, the unconformity corresponding in time, as it does in magnitude, with the post-

Laramie unconformity, and the upper coal-bearing rocks with the post-Laramie formations of this basin. When the evidence of the fossil plants is thoroughly weighed this assignment, so satisfactory to the stratigrapher, may require modification.

PLANT FORMS FROM THE RATON COAL FIELD, NEW MEXICO

(Identified by F. H. Knowlton)

	Cretaceous (below unconformity).	Found in Laramie formation of Denver basin.	Post-Laramie (above unconformity).	Found in Post-Laramie formations of Denver basin.
Anemia perplexa (Hollick)	....	....	×	....
Aralia sp	×	....	×	....
Aspidium (?) sp	....	....	× (?)	....
Carpites sp	×	....	×	....
Cissus sp	....	....	×	....
Ficus lanceolata Heer	×	×	× (?)	....
Ficus speciosissima (?) Ward	× (?)	....	× (?)	....
Ficus spectabilis (?) Lesq	....	×	× (?)	×
Ficus trinervis Kn	×	×	×	×
Ficus sp	×	....	×	....
Flabellaria eocenica Lesq	....	×	×	×
Geonomites ungeri Lesq	....	....	×	....
Juglans sp. (?)	× (?)	....	× (?)	....
Laurus sp	×	....	×	....
Magnolia hilgardiana Lesq	....	....	×	....
Magnolia lesleyana Lesq	....	....	×	....
Magnolia tenuinervis Lesq	....	....	×	×
Magnolia sp	....	....	×	....
Nelumbo (?) sp	....	....	× (?)	....
Palmocarpon commune Lesq	....	....	×	×
Platanus aceroidos Gopp	....	....	×	×
Platanus guillelmæ Gopp	×	....	×	×
Platanus haydenii Newb	....	....	×	×
Platanus raynoldsii Newb	....	....	×	×
Platanus rhomboidea (?) Lesq.	....	....	× (?)	×
Platanus sp	....	....	×	....
Quercus haidengeri or n. sp	....	....	×	×
Quercus sp	×	....	....	....
Rhamnus salicifolius (?) Lesq.	× (?)	....	× (?)	....
Salix (?) sp	× (?)	....	....	....
Sapindus (?) sp	× (?)	....	....	....
Sequoia brevifolia (?) Lesq	× (?)	....	....	....
Vitis olriki (?) Heer	....	....	× (?)	....
Viburnum montanum (?) Kn.	× (?)	....	....	....

These determinations were made more than a year ago, since which time Doctor Knowlton has visited portions of the Raton Mesa and Canon City coal fields and collected additional material, which seems to indicate that the horizons here referred to post-Laramie may be of Laramie age. Pending the full study of this, together with all previous collections, he desires to hold the matter of final settlement in abeyance.

Summary of Plant Forms named in the preceding Table.

	Cretaceous (Laramie or older).	Post-Laramie.
Number of forms collected in the Raton field in 1908....	15	29
Number of doubtful species...........................	4	6
Number of positively identified species...........	3	13
Number of positively identified species found also in the Post-Laramie formations of the Denver Basin........	2	9

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PROPOSED CLASSIFICATION OF CRYSTALS BASED ON THE RECOGNITION OF SEVEN FUNDAMENTAL TYPES OF SYMMETRY[1]

(*Read before the Society December 31, 1908*)

BY CHARLES K. SWARTZ

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[1] Manuscript received by the Secretary of the Society July 31, 1909.

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INTRODUCTION

The modern classification of crystals into thirty-two groups is a highly important addition to our knowledge of the subject of crystallography, as well as a valuable contribution to the field of natural science.

We are indebted to many investigators for the development of this classification, chief among whom are Hessel, Bravais, Moebius, Gadolin, Curie, Fedorow, and Schoenflies. While Hessel was the originator of the classification, his work, unfortunately, was long neglected, and it was not until Gadolin, Schoenflies, and others had given independent developments of the subject, that crystallographers came to recognize the importance of their work.

While the classification of crystals into thirty-two groups rests on a sound and philosophical basis, it is probable that many have found its presentation, especially to elementary students, attended by certain difficulties, chief among which are the multiplicity of the types of symmetry of the thirty-two groups and the consequent lack of a clear conception on the part of the student of the relations which exist among them.

Though developed, as so elegantly expressed by Gadolin, by the application of a single principle, the method by which this has been done historically is too intricate to be employed in an elementary presentation of the subject. If, however, the use of this principle is abandoned and the groups of symmetry are treated as separate units, the student fails to comprehend one of the most important elements in the classification of crystals, namely, the development of the thirty-two groups by the application of a single principle—a result which seems to the author most unfortunate and which leads to embarrassment, because of the failure to perceive the larger relations which exist among the groups of symmetry as well as the unity of the subject.

It is the purpose of the author to give, in the following communication, an elementary development of the thirty-two groups of crystals which leads to the recognition of seven fundamental types of symmetry of crystals. It is believed that the recognition of these seven types of symmetry not only greatly simplifies the discussion, but emphasizes relations among the groups of crystals which have not hitherto been clearly recognized.

These seven types of symmetry were recognized in part by Hessel, who defined them by his seven types of axes and who referred to them all crystals with a principal axis. While he developed this classification consistently in crystals with a principal axis, he did not succeed in following it in the Isometric system, where he adopted another principle. Had he recognized these types in that system also, he would have largely anticipated the results here given. The author's development is, however, independent of that of Hessel, with whose methods he was not acquainted at the time of its origination, while the method used differs from Hessel's in its simplicity and brevity. It is, however, encouraging to find so large an agreement between the results obtained by Hessel and by the writer.

We are especially indebted to Schoenflies, from the reading of whose work we were led to the conceptions here presented and with whose method of development that proposed has some features in common.

Certain conclusions of the author are related to those of Miers. They were, however, developed before the appearance of that author's work.

These types have been more or less clearly recognized by many in closely related systems, such as the Trigonal, Tetragonal, and Hexagonal, but their occurrence in all systems does not seem to have been shown by others before this.*

The discussion will consist of two parts:

I. A proposed classification of crystals.

II. An historical review, giving an outline of the earlier development of the thirty-two groups and their relation to the author's results

PART I: PROPOSED CLASSIFICATION OF CRYSTALS

PRELIMINARY CONSIDERATIONS

Before discussing the proposed classification it is desirable to present certain preliminary considerations.

Definitions—Singular direction.—A singular direction in a crystal is one about which the arrangement of parts and properties differs from that about every other direction in the crystal. Thus, in a crystal of the Hexagonal system, the *c* axis is a direction about which the properties differ from those about every other direction in the crystal—that is, it is a singular direction and is not duplicated by any other line.

Elements of symmetry.—It is often convenient to have a word which includes both axes and planes of symmetry. We will define an axis or plane of symmetry as an element of symmetry (the "basis of symmetry" of Moebius).

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* This classification is published only after it has been in use in teaching for a number of years and its value shown by experience.

Theorems.—Axes or planes of symmetry must necessarily intersect symmetrically, since all parts are symmetrically disposed with reference to them. We have the following theorems concerning their combinations:

1. The least number of axes of symmetry that can enter into combination is three. Two only can not combine.[2]
2. If a singular axis be intersected by other axes, then the latter are (*a*) in number equal to period of singular axis; (*b*) in period, two-fold; (*c*) in position, perpendicular to the singular axis. (See figure 1, where a four-fold axis is intersected by 4 two-fold axes.) Proof:
   - (*a*) If lateral axes are present, their number equals period of singular axis, since all parts are repeated about any axis as often as its period. For example, three axes occur about a three-fold axis, four about a four-fold axis, etcetera.
   - (*b*) If the lateral axes were not two-fold, the singular axis would be repeated in a new position—that is, it would not be singular. Thus it would be repeated three times about a three-fold axis, etcetera.

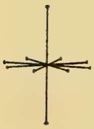

FIGURE 1.—Singular axis with 4 lateral axes.

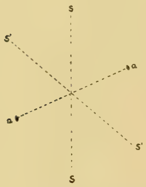

FIGURE 2.—Repetition of singular axis about oblique axis.

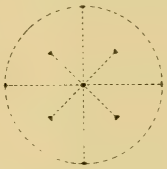

FIGURE 3.—Trigonal axes developed by equal rectangular axes.

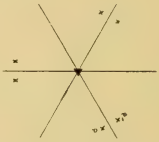

FIGURE 4.—Axis of symmetry developed at intersection of symmetry planes.

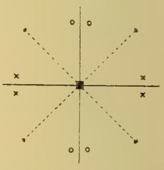

FIGURE 5.—Alternating axis developed by alternating axes and symmetry planes.

   - (*c*) If the accessory axes were oblique to the singular axis, the latter would be repeated in a new position—that is, it would not be singular. Thus, in figure 2, the singular axis *SS* would be rotated to position *S'S'* about an oblique axis *aa* and no longer be singular.
3. Intersection of equal axes.—If equal axes intersect, then
   - (*a*) The least number of such axes is three. (See theorem 1.)
   - (*b*) If the three axes are equal, they are rectangular, since each axis is equally distant from the others if all are equal—that is, perpendicular to them.
   - (*c*) If rectangular, their periods can be two or four only. Three and six-fold axes can not produce 90 degree positions, since they must intersect at 120 or 60 degrees.
   - (*d*) Four trigonal axes are present, equally distant from the three equal axes and intersecting in the center of figure. They are the signs of the equality of the three axes. (See projection, figure 3.)
4. Intersection of axes and planes of symmetry.
   - (*a*) The intersection of several axes of symmetry lying in one plane produces an axis of symmetry at their point of intersection whose period equals their number. (See figure 1.) This is the converse of theorem 2*a*.

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[2] See proof of this very elementary proposition in Groth's Physikalische Krystallographie, fourth edition, 1895, pp. 315-316.

(*b*) Several planes of symmetry intersecting in one line produce an axis of symmetry at their intersection whose period equals the number of intersecting planes. Thus, in figure 4 it is readily seen that the intersection of the three planes will repeat the point *a* at *a'*, and this pair of points will appear in three similar positions—that is, they are repeated three times about the line of intersection, which becomes, therefore, a three-fold axis.

(*c*) The intersection of alternating planes and axes in one line produces an axis of alternating symmetry at their intersection whose period equals the number of intersecting axes and planes. An ordinary axis of half that period will coincide with the alternating axis. This law is readily seen by the repetition of the point *x* in figure 5.

We may express the theorems *a*, *b*, *c* by the statement that the intersection of several axes or planes of symmetry produces an axis of symmetry at their intersection whose period equals the number of intersecting elements. If axes or planes only intersect, it is an ordinary axis; if alternating axes and planes intersect, it is an alternating axis.

5. Possible periods.—The only periods axes of symmetry can possess in crystals are 2, 3, 4, 6. This springs directly from the law of the Rationality of Parameters. Its proof is too full to be given here. (See Groth's Physikalische Krystallographie, fourth edition, 1895, page 313.)

DEVELOPMENT OF CLASSIFICATION

Basis of classification.—The basis of classification is symmetry. Crystals have been classified upon the basis of the crystallographic axes, as is done in the ordinary definition of the systems of crystals. These are, however, imaginary mathematical lines, existing only subjectively in the mind of the observer and developed by him for convenience sake. They are not present objectively in the crystal and can not, therefore, form a natural basis for the classification of crystals. That they are arbitrarily determined is seen by the fact that the same crystal may be referred to several different axes, as in the use of the axes of Miller and Bravais in the Trigonal system.

Symmetry affords a natural basis for the classification of crystals, being expressed by the elements of symmetry which are objectively present in the crystal. Moreover, symmetry is expressive not only of the geometrical form, but of the relations of the physical properties as well, and probably springs from the arrangement of the atoms and molecules in the crystal.[3] It is, moreover, the basis upon which the modern classification has been historically developed. It is, therefore, that which is accepted in the following discussion.

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[3] See recent articles of Barlow and Pope in Journal of the Transactions of the Chemical Society of London, vol. 89, 1906, p. 1675, and vol. 97, 1907, part ii, pp. 1150-1214. See also abstracts in American Chemistry Journal, vol. xxxvii, 1907, p. 638, and vol. xlii, 1909, p. 158.

Types of symmetry.—Symmetry may be defined as the repetition of similar parts and properties in a crystal. It may be produced in two fundamental ways:

I. By rotation about an axis, termed symmetry by rotation.

II. By reflection about a plane or planes, termed symmetry by reflection.

A third type (III) is produced by the combination of simultaneous rotation and reflection by which points, in rotating, oscillate alternately from upper to lower positions in a crystal, and vice versa. Such an axis may be termed an axis of combined rotation and reflection, or, more simply, an alternating axis. It may be considered a combined axis and plane normal to it. This is the "zusammengesetzte" symmetry of Fedorow.

We will now consider classes which develop in each type of symmetry.

FIGURE 6.—Axial class.

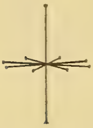

FIGURE 7.—Polyaxial class.

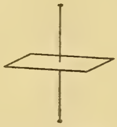

FIGURE 8.—Orthoaxial class.

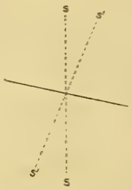

FIGURE 9.—Repetition of singular axis by oblique plane of symmetry.

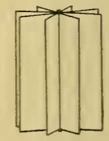

FIGURE 10.—Hedral class.

Development of groups and classes of crystals.

I. Symmetry by rotation. Rotation may be about one axis or many axes.

1. Rotation about one axis—*Axial class** (figure 6).

   Rotation may occur about one axis, producing crystals having a single axis of symmetry. The axis may have periods of 2, 3, 4, 6 only, according to the law of the Rationality of Parameters, producing four groups of crystals. (See table, page 377, for summary.)

   All these crystals have one axis of symmetry and are singly terminated. The name suggested for this class is Axial (*axon* = an axis).

2. Rotation about many axes—*Polyaxial class* (figure 7).

   Rotation may occur about many axes, producing crystals containing many axes of symmetry. Two possibilities are presented:

   a. A singular axis is present. Its periods may be 2, 3, 4, 6, according to the law of the Rationality of Parameters. The number of the lateral axes equals period of singular axis.

   b. No singular axis is present. There are three equal axes whose periods are 2 or 4.

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* This class may also be termed Monaxial instead of Axial, since it has only one axis of symmetry and all of its crystals are singly terminated.

These crystals are doubly terminated, producing right- and left-handed forms which are enantiomorphous, and all manifest circular polarization. They are termed Polyaxial (*polus* = many, *axon* = an axis).

II. Symmetry by reflection about planes. The second fundamental type is symmetry by reflection.

Method of development.—It has already been shown that when planes of symmetry intersect they produce an axis of symmetry at their intersection. It is therefore necessary that the axes so formed should be identical with those already discussed. The simplest way of developing these classes, therefore, is to take the preceding axis and pass planes of symmetry through them, employing first one axis, then many axes.

A. One axis.—Planes may be passed through one axis in two positions.

3. Plane normal to the axis—*Orthoaxial class* (figure 8).

The axis may possess the periods 2, 3, 4, 6, giving rise to four groups. These crystals are doubly terminated, the upper faces being directly over the lower while the plane is normal to the axis. The class is hence termed Orthoaxial (*orthos* = perpendicular, and *axon* = an axis).

A plane of symmetry can not pass obliquely to a single axis, otherwise the axis would be doubled by reflection, as shown in figure 9, where the axis *S S* is reflected to position *S′ S′*—that is, the crystals would no longer possess a single axis. One other possibility, therefore, remains.

4. Planes parallel to the axis—*Hedral class** (figure 10).

Planes of symmetry are passed parallel to the axis which is produced by their intersection, its period equaling the number of intersecting planes.

These crystals are singly terminated and have their faces in pairs in the general form (*mPn*). They possess planes of symmetry intersecting in one axis. The class is termed Hedral (*hedra* = a plane), since the axis is but the result of the intersection of the planes.

B. Many axes.—We may now pass planes through many axes. Planes may be passed through them in two positions only, either coinciding with the axes or alternating with the axes.

5. Planes coinciding with the axes—*Orthohedral class*† (figure 11).

Here the planes pass through the axes which are formed at their intersections. Having many axes, two possible cases present themselves:

a. A singular axis is present with periods of 2, 3, 4, 6.

---

* This class may also be termed Monaxihedral (having planes intersecting in one axis) or, for simplicity, Monohedral (singly terminated pyramids of the hedral type).

† This class may also be termed Polyhedral; that is, having many planes of symmetry.

b. No singular axis is present. Three equal axes with periods of 2 or 4.

Crystals of this class are doubly terminated, the faces of the upper pyramid being directly over those of the lower. Its symmetry may be derived from that of the Hedral class by passing a plane of symmetry normal to the planes of symmetry of that type. It is hence named Orthohedral (*orthos* = perpendicular, *hedra* = a plane).

6. Planes alternating with the axes—*Amebahedral class* (figure 12).

Vertical planes of symmetry may be passed between the lateral axes with which they then alternate, developing an alternating axis at their intersection. Since the smallest number of lateral axes is two, alternating with two planes, the lowest possible period is 4. Having many axes, two possibilities are presented:

a. A singular axis is present with periods of 4 or 6.

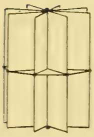
FIGURE 11.—Orthohedral class.

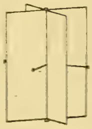
FIGURE 12.—Amebahedral class.

FIGURE 13.—Amebaxial class.

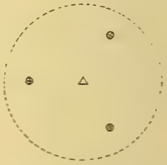
FIGURE 14.—Three-fold alternating axis producing orthohedral symmetry.

b. No singular axis present. Three equal axes occur with periods of 4.

These crystals possess alternating vertical planes and horizontal lateral axes of symmetry, while their faces alternate about the vertical axis. They are hence termed Amebahedral (*amoibos* = alternate, *hedra* = a plane).

This manifestly exhausts all possible types of symmetry due to reflection about planes.

III. Symmetry by combined rotation and reflection. In addition to the preceding, it is possible to combine rotation and reflection simultaneously in one act, producing a third type of symmetry. This is the combined (zusammengesetzte) symmetry of Fedorow. A single class develops here.

7. *Amebaxial class* (figure 13).

These crystals are without ordinary axes or planes of symmetry, but possess a single axis of alternating symmetry. This fact may also be expressed by stating that they have a combined axis and plane of symmetry normal to it, or, more simply, that they have a single axis of alternating symmetry.

This axis can have periods of 2, 4, 6 only. A three-fold alternating axis is impossible. If assumed, it will produce faces which are directly over each other—that is, they will not be alternating. (See projection, figure 14.)

Crystals of this class possess an alternating axis about which the faces of the crystals alternate, and are hence named Amebaxial (*amoibos* = alternating, *axon* = an axis).

The above manifestly exhausts all possible combinations of axes and planes of symmetry with periods of 2, 3, 4, 6, producing thirty groups of symmetry. Two other types of symmetry are possible:

1. Forms possessing a plane of symmetry only. They may be viewed as containing a one-fold axis parallel to the plane, and hence referred to the Hedral class—one-fold.
2. Forms without symmetry, the asymmetric group of Groth. They are reproduced by a rotation of 360 degrees about a one-fold axis, and hence may be referred to the Axial class—one-fold.

This manifestly exhausts all possible types of symmetry produced by rotation and reflection in forms having periods 1, 2, 3, 4, 6. Thirty-two groups of symmetry are thus seen to be developed, occurring in seven classes.

Summary of development.—The results reached and the periods of each class are exhibited in the following table:

	Period of Axis.	
	Singular axis.	No singular axis.
I. Symmetry by rotation about an axis.		
1. One axis—*Axial*	1, 2, 3, 4, 6	
2. Many axes—*Polyaxial*	2, 3, 4, 6	2, 4
II. Symmetry by reflection about planes.		
A. One axis:		
3. Plane normal to axis—*Orthoaxial*	2, 3, 4, 6	
4. Planes parallel to axis—*Hedral*	1, 2, 3, 4, 6	
B. Many axes:		
5. Planes coincident with axes—*Orthohedral*	2, 3, 4, 6	2, 4
6. Planes alternating with axes—*Amebahedral*	–, –, 4, 6	–, 4
III. Symmetry by combined rotation and reflection.		
7. Alternating axis only—*Amebaxial*	2, –, 4, 6	

REFERENCE OF THE CLASSES TO THE ACCEPTED SYSTEMS OF CRYSTALS

We may inquire what relation the preceding development bears to the crystal systems. An examination of the above table shows that the groups fall into natural assemblages, based upon the character and period of their axes of symmetry. These are the accepted systems, as follows:

1. Crystals possessing no singular axis of symmetry, characterized by three equal axes, constitute the Isometric system, which develops in two- and four-fold divisions.
2. Six-fold groups—Hexagonal system.
3. Four-fold groups—Tetragonal system.
4. Three-fold groups—Trigonal system.

The remaining two- and one-fold groups might have been classified into two- and one-fold systems respectively. They have, however, been divided according to the number of fixed directions of symmetry (determining the number of their rectangular directions), as follows:

5. Possessing three fixed directions of symmetry—Orthorhombic system.
6. Possessing one or two fixed directions of symmetry—Monoclinic system.
7. Possessing no fixed direction of symmetry—Triclinic system.

The various systems are thus seen to spring from the above development.

The members of one system and one class constitute a group of crystals. The relations of the various classes and systems are shown in plates I and II.[4] The first plate shows the general form (*mPn*) in each group; the second the spherical projections of the symmetry of each group. The character of the symmetry of each class is illustrated in the first vertical column.

CHARACTERISTICS OF THE SEVEN CLASSES

The characteristics of the seven classes may be exhibited by arranging them in a slightly different manner from that in which they were developed. They are seen to comprise two distinct types—(I) axial, (II) hedral.

I. *Axial classes.*

The axial classes have pyramids produced by rotation. They are characterized by the fact that the faces of the general form (*mPn*) are single, never in pairs, about the axis of rotation. They develop first, second, and third order forms, the latter being both right- and left-handed.

1. The *Axial class* contains singly terminated pyramids possessing a single axis of symmetry. The other axial classes consist of two such pyramids joined base to base. This may be done in three ways. The faces of the upper pyramid may be
2. Directly over those of the lower pyramid—*Orthoaxial class;*
3. Obliquely over those of the lower pyramid, being rotated either to the right or the left hand, producing right- and left-handed forms—*Polyaxial class;*
4. Alternating with those of the lower pyramid (the faces of the upper pyramid being over the edges of lower pyramid)—*Amebaxial class.*

II. *Hedral classes.*

The hedral classes, on the contrary, have pyramids produced by reflection about vertical planes of symmetry (as usually held). The faces of the general form (*mPn*) hence occur in pairs about these planes, producing di-forms (di-pyramids, scalenohedra, etcetera).

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[4] The monoclinic crystals are drawn with axis of symmetry vertical to show their relations better to crystals of other systems.

5. The *Hedral class* consists of singly terminated pyramids having faces in pairs. Two such pyramids may be joined base to base, producing the other hedral classes. The faces of the upper pyramid may be
6. Directly over those of the lower pyramid—*Orthohedral;*
7. Alternating with those of the lower pyramid—*Amebahedral.*

   The oblique position corresponding to that of the Polyaxial class can not exist in this type, since the planes of symmetry of the upper and lower pyramids would not coincide, violating the law of Parallel Directions.

These relations are exhibited in the following tables:

Table showing Forms of Classes

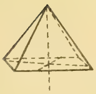
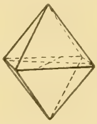
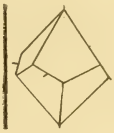
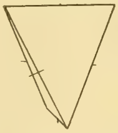
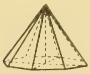
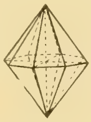
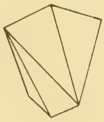
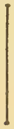
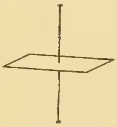
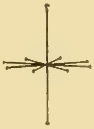
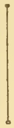
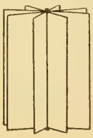
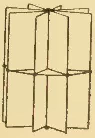
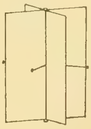
		Doubly terminated		
	Singly terminated	Direct (Horizontal plane of symmetry)	Oblique (Horizontal axes of symmetry)	Alternate (Alternating axis)
	Axial	Orthoaxial	Polyaxial	Amebaxial
Axial (Faces single in mPn)				
	Hedral	Orthohedral		Amebahedral
Hedral (Faces in pairs in mPn)				

Table showing Symmetry of Classes

		Doubly terminated		
	Singly terminated	Direct (Horizontal plane of symmetry)	Oblique (Horizontal axes of symmetry)	Alternate (Alternating axis)
	Axial	Orthoaxial	Polyaxial	Amebaxial
Axial (Faces single in mPn)				
	Hedral	Orthohedral		Amebahedral
Hedral (Faces in pairs in mPn)				

An examination of the above table shows that the seven classes fall into pairs of two members each, which differ in that the axial have single and the hedral double faces in the general form (*mPn*). Thus in the Orthoaxial class we have third order pyramids, and in the Orthohedral class di-pyramids; the third order rhombohedron of the Amebaxial class corresponds to the hexagonal scalenohedron of the Amebahedral class having faces in pairs, etcetera. There is, however, no hedral class corresponding to the Polyaxial class, which thus stands alone.

LARGER DIVISIONS OF CRYSTALS

In addition to the systems and classes, the above development shows (see plates I and II) that certain larger divisions occur, expressing the fundamental geometrical and physical properties of crystals. These major divisions are three in number. We here term them the Isometric, Dimetric, and Trimetric divisions respectively.

Isometric division.—This comprises all crystals having no singular direction. Their crystallagraphic axes have hence one unit of length. Their optical properties are alike in all directions and their elasticity figure is a sphere.

Dimetric division.—This comprises crystals having one singular direction. Their crystallographic axes have hence two units of length. They are optically uniaxial. Their elasticity figure is an ellipsoid.

Trimetric division.—This comprises crystals having three or more singular directions; hence their crystallographic axes have three units of length. They are optically biaxial. Their elasticity figure is the triaxial ellipsoid of Fresnel.

These divisions correspond to and express the fundamental physical and geometrical properties of crystals. They are the same as those developed by Hessel, although expressed in other terms. We are thus led by the preceding development to divisions representing the larger geometrical and physical units in crystals.

INTEGRITY OF THE SEVEN CLASSES OF CRYSTALS

The foregoing discussion shows that the seven classes of symmetry are well defined and natural units each containing forms having a single type of symmetry. This conclusion is supported by the following considerations:

1. Their development, already sketched, shows this fact.

2. It is also shown by the fact that the members of one class possess common geometrical properties. Thus the Scalenohedral group of the Hexagonal system, the Scalenohedral group of the Tetragonal system, and the Hextetrahedral group of the Isometric system are members of one

class. All are very closely related and form a natural unit. The same is true of the members of other classes. The Isometric groups do not differ in any essential way from the other members of the classes to which they are referred, the only difference being the repetition of the faces about the three-fold axis.

3. Again, all the members of one class are closely related physically. Thus all the Polyaxial groups manifest circular polarization, the members of the Hedral class show hemimorphic physical properties, etcetera.

4. The members of each class possess a single type of symmetry, as seen in the spherical projections of plate 31.

Definition of class.—For the unit so described we propose the term *class.* It may be defined as follows: *A class of crystals is the sum of all crystals having similar combinations of elements of symmetry.* Thus all the members of the Axial class have one axis of symmetry; members of the Orthoaxial class, one axis and a plane normal to it, etcetera.

The discussion given above is seen to lead to an elementary development of the thirty-two groups, the recognition of seven classes of crystals, the development of the seven systems, and the recognition of the larger and more fundamental divisions which correspond with the physical and geometric properties of crystals.

ELEMENTARY DEVELOPMENT

It is possible to give a still simpler development of the preceding classification, for the use of elementary students, which it may be desirable to outline here, in addition to that already presented. Although certain of its features have been stated in the foregoing discussion, they will be restated here for the sake of clearness and brevity.

Symmetry has been defined as the repetition of similar parts and properties in a crystal. It may be of two types:

I. Symmetry by rotation about an axis.
II. Symmetry by reflection about a plane or planes.

In the first type planes occur singly, about the axis of rotation. In the second type planes occur in pairs in the general form (nPn).

I. Symmetry by rotation.—If an inclined plane be rotated about a vertical axis, it will produce a singly terminated pyramid, the number of whose sides equals the period of the axis. It may be rotated into any position about the vertical axis-producing pyramids of the first, second, and third orders. *Axial class.*

Two such pyramids may manifestly be joined base to base, producing double pyramids. This combination may be effected in three different ways:

1. The faces of the upper pyramid may be directly over those of the lower pyramid. This type has a horizontal plane of symmetry and is called the *Orthoaxial class.*

2. The faces of the upper pyramid may be above the edges of the lower pyramid—that is, the faces of the upper and lower pyramid alternate about the vertical axis, which then becomes an alternating axis—*Amebaxial class.*

3. The upper pyramid may be obliquely over the lower pyramid, being turned through some angle intermediate between those of the two preceding classes. Such rotation may be either to the right hand or the left, giving two kinds of forms, termed right- and left-handed respectively. They possess horizontal axes of symmetry—*Polyaxial class.*

II. Symmetry by reflection about a plane or planes.—Let several planes intersect in a vertical axis. The period of the axis will then equal the number of intersecting planes of symmetry.

Any inclined crystal face will be reflected about the planes of symmetry, producing a singly terminated pyramid whose faces are in pairs, the number of pairs being equal to the number of the vertical planes of symmetry—*Hedral class.*

Two such pyramids may be combined base to base, producing doubly terminated pyramids. This may occur in two ways:

1. The upper pyramid may be directly over the lower. A horizontal plane of symmetry develops, while axes of symmetry are developed at the intersection of the planes of symmetry, the axes being precisely like those of the Polyaxial class—*Orthohedral class.*

2. The faces of the upper pyramid may be over the edges of the lower pyramid—that is, the faces of the upper and the lower pyramid alternate about the vertical axis. Horizontal axes of symmetry develop between the vertical planes of symmetry. The vertical axis is therefore an alternating axis whose least possible period is four, since the smallest possible number of lateral planes plus axes is four (two of each)—*Amebahedral class.*

The intermediate position, corresponding to that of the Polyaxial class, can not occur, since the planes of symmetry of the upper and lower pyramid would not coincide, violating the law of Parallel Directions. There are thus seven classes of symmetry, and seven only, possible.

Periods of the axes of symmetry.—It will be observed that three of the classes—Polyaxial, Orthohedral, and Amebahedral—have many axes of symmetry. All classes may develop a singular axis with periods of 2, 3, 4, 6, and the three classes with many axes may develop in addition three equal axes having periods of 2 or 4, save that the alternating types have no three-fold period and the Amebahedral class no period less than four. In addition to the preceding we may also have one-fold Axial and one-fold Hedral forms.

Thirty-two groups are developed in this manner. They are summarized in the following table, the periods possible in each class being given below its name.

	Singly terminated	Doubly terminated		
		Direct	Oblique	Alternate
Axial	Axial	Orthoaxial	Polyaxial	Amebaxial
	1, 2, 3, 4, 6	2, 3, 4, 6	2, 3, 4, 6, 2, 4	2, – 4, 6
Hedral	Hedral	Orthohedral	....	Amebahedral
	1, 2, 3, 4, 6	2, 3, 4, 6, 2, 4	....	4, 6, 4

The reference of the groups to the various systems may then be developed as outlined in the preceding paragraphs.

INFERENCES

It may be of interest to give certain deductions springing from the preceding discussion.

Relative rank of classes and systems.—The classes appear to be more natural in character than the systems. They are certainly less artificial than the systems, if the latter are made, as has been generally the case, to depend upon the crystallographic axes, which are imaginary lines subjectively present in the mind of the student. This is well seen in the difference in usage in the Trigonal system, where the axes of Miller or Bravais can be employed equally well. It is also quite possible to refer the Hexagonal and Trigonal forms to orthorhombic axes, as frequently done by Barlow and Pope in their recent paper, "The relation of crystalline form and chemical constitution."[5] The classes, on the contrary, depend upon the axes and planes of symmetry objectively present in the crystal, and are hence natural units.

Relative rank of the systems.—The various systems do not appear to be coordinate in value, but represent divisions of different rank. Thus the Isometric system is coordinate with the Dimetric division comprising crystals of the Trigonal, Tetragonal, and Hexagonal systems, and also with the Trimetric division. This is also shown by the optical properties, in which respect the Isometric system corresponds to the Uniaxial and Biaxial divisions of crystals. Like those divisions, it may be subdivided on the basis of period, yielding two-fold and four-fold sections.

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[5] Journal of the Transactions of the Chemical Society, vol. 91, 1907, part 2, pp. 1150-1214, and vol. 94, 1908, p. 1528.

Again, the Orthorhombic, Monoclinic, and Triclinic crystals are divided on a different basis from that employed in making the subdivisions of dimetric crystals. The systems therefore appear to differ in rank.

Relations of the rhombohedral and scalenohedral groups.—These groups contain both a three-fold common and a six-fold alternating axis, and hence may be referred, on the basis of period, to either the Trigonal or Hexagonal system. While they have generally been referred to the Trigonal system, it seems clear to the author that their natural place is in the Hexagonal system, where he has placed them, for the following reasons:

The group containing the third order sphenoid of the Tetragonal system is unquestionably four-fold. Dana makes it two-fold; Groth, four-fold. Groth's position seems correct. It possesses no center or planes of symmetry, and it is impossible to develop it about an axis of two-fold period. If the third order sphenoid, possessing four faces, is four-fold, the analogous third order rhombohedron, with six faces, should have a higher period, becoming six-fold. It is quite clear that the third order rhombohedron bears the same relation to the Hexagonal system that the third order sphenoid does to the Tetragonal system. The Tetragonal character of the third order sphenoid is unquestioned. A consistent interpretation would seem to refer the third order rhombohedron to the Hexagonal system.

Again, the Tetragonal and Hexagonal scalenohedra are the precise analogues of the third order sphenoid and third order rhombohedron, and their position is determined in the same manner. It seems fitting that the analogous forms of the Tetragonal and Hexagonal systems should be classified in the same manner.

The third order rhombohedron can not be developed about a trigonal axis without an appeal to a center of symmetry. It will be noticed that, in all other forms, the results obtained by the use of a center of symmetry spring directly from the axes and planes of symmetry as here employed. It does not seem desirable to appeal to a center of symmetry in this case only.

Again, that the alternating axis is the dominant axis is indicated by the fact that the highest occurring period, six-fold, is that of the alternating axis, in harmony with the law of the Rationality of Parameters.

It thus seems best to refer these groups to the Hexagonal system, giving a consistent development to Trigonal, Tetragonal, and Hexagonal systems and bringing out the evident close analogy between them.

Center of symmetry.—The development employed has rendered it unnecessary to use the center of symmetry as an independent element of symmetry. It is manifestly secondary, being produced by the planes and axes of symmetry. It is unnecessary to retain it as a distinct element of symmetry.

ADVANTAGES OF THE METHOD

The classification outlined in the foregoing discussion is believed to possess certain advantages.

It is based on symmetry, the basis of the modern development of crystallography.

It recognizes the likeness of closely related groups and points out the analogies between them.

It recognizes seven instead of thirty-two units and develops all by one general method.

The name of the class suggests both the symmetry and crystal form. It introduces few new names, and these it is believed are significant. It does not displace accredited names.

It expresses the larger physical and geometrical relations which exist among crystals.

It is in harmony with the fundamental mathematical development of the subject.

It is elementary, and is readily followed by the elementary student.

PART II: HISTORICAL REVIEW

REVIEW OF THE DEVELOPMENT OF THE THIRTY-TWO GROUPS OF CRYSTALS

Work of previous investigators.—The classification of crystals into thirty-two groups constitutes one of the most important contributions to the science of crystallography. It was developed by the labors of a number of independent investigators, chief among whom are Hessel, Bravais, Moebius, Gadolin, Curie, Fedorow, Minnigerode, and Schoenflies. An outline of their work will be given and its relation shown to the classification proposed in the preceding pages. Their results will be discussed somewhat more fully because of the great historic interest of the subject.

All of these investigators have had one aim, to predict all forms of crystals which may possibly occur. The basis of their investigations has been the conception of symmetry, of which all have recognized two fundamental types: (1) symmetry produced by a repetition of identical parts by rotation; (2) symmetry produced by the repetition of similar parts by reflection, together with various combinations of these two processes.

With respect to their methods, the investigators form two classes: (1) those who have first sought to develop all possible types of symmetrical figures, and then to determine which of these may occur in crystals, in harmony with the law of the Rationality of Parameters, the fundamental law of crystallography; (2) those who have sought to develop only the forms which are possible in crystals under the above named law.

To the first class belong Hessel, Bravais, Moebius, Curie, Fedorow, and Minnigerode; to the second, Gadolin and Schoenflies.

Hessel.—The founder of the modern classification of crystals is J. F. C. Hessel, whose results were published in an article entitled "Krystall," in Gehler's Physikalisches Worterbuch, in the year 1830.[6]

Unfortunately Hessel's results long rested in obscurity and were practically overlooked. It is only recently that they have begun to be appreciated at their true worth.

Hessel based his discussion upon the conception of symmetry, of which he recognized two types, ebenbildlich (having the same form) and gegenbildlich (likeness by reflection).[7]

Hessel's method is to develop first all possible symmetrical figures, and then, secondly, to determine which of these are possible in crystals.[8] To do this he shows first that there are seven types of axes about which all symmetrical figures may be developed. The types are as follows:[9]

Types of Axes

- Ends unlike (ungleichendig).
  - Simple (einfach).
  - Double (zweifach).
- Ends alike (gleichendig).
  - Forms opposite (gleichstellig) ....
    - Simple (einfach).
    - Double (zweifach).
  - Forms not opposite (ungleichstellig) ....
    - Alternate (gerenstellig).
      - Simple (einfach).
      - Double (zweifach).
    - Oblique (ebenbildlich).
      - Simple (einfach).

The axes are classified accordingly as they are dissimilarly terminated (ungleichendig) or similarly terminated (gleichendig). The latter are divided into those in which the upper faces directly overlie the lower (gleichstellig) or not. The last type is subdivided into those in which the upper faces alternate with the lower (gerenstellig), or are obliquely over the lower, producing enantiomorphous forms (ebenbildlich). He recognizes thus four major types of axes: (1) singly terminated, (2) doubly terminated direct, (3) alternate, (4) oblique. Each of the first three types may coincide with a plane of symmetry or not, producing faces which are in pairs (zweifach) or single (einfach).

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[6] Bd. v, Ab. ii, pp. 1023-1360.

A separate edition of this article was issued in 1831 under the title "Krystallometrie oder Krystallonomie und Krystallographie." This work is reprinted in Ostwald's "Klassiker der exakten Wissenschaften," no. 88, 1897. An admirable review of Hessel's results is given by L. Sohncke, "Die Entdeckung des Eintheilungsprincips der Krystalle," Zeitschrift für Krystall., bd. 18, pp. 486-498, 1891.

[7] Article Krystall, cited above, p. 1035. Reprint, vol. i, pp. 20-21.

[8] He develops his results by means of radii ("strahlen"), which are lines drawn from the center of the figure to the symmetrical parts. He is thus able to discuss the position of these lines rather than the parts of the figures. Hessel does not recognize planes of symmetry, but develops the figures about axes which comprise in reality both axes and planes of symmetry.

[9] Article Krystall, pp. 1059-1060. Reprint, vol. i, pp. 44-45. See Sohncke, Zeitschrift für Krystall., bd. 18, p. 488, 1891.

All possible symmetrical forms are next developed about the seven types of axes, by which means he arrives at all possible symmetrical figures.[10]

Hessel now develops the law of the Rationality of Parameters,[11] which he terms Das Gerengesetz, and shows that according to this the only axes possible in crystals are those possessing periods of 1, 2, 3, 4, 6. Applying this law to the preceding forms, he shows that all crystals fall into 32, and only 32, groups of symmetry, of which a summary is given on pages 1280 to 1284 of his article.[12]

He divided all the groups, save those of the Isometric system, into seven types, according to the character of their dominant axis. Unfortunately he failed to carry his classification into the Isometric system, but was led to adopt another principle in it, namely, the number of similar radii in the crystal. The Isometric system was thus termed the eight-rayed (8-strahlig) system, its groups being as follows:[13]

Zweifach 8-strahlig (Hexakisoctahedral of Groth).
Einfach 8-strahlig (Pentagonal Icositetrahedral of Groth).
Zweifach 4-strahlig (Hexakistetrahedral of Groth).
Einfach 4-strahlig (Tetart. Pent. Dodecahedral of Groth).
Zweimal 4-strahlig (Dyakisdodecahedral of Groth).

Had he succeeded in carrying his seven divisions into the Isometric system he would have largely anticipated the author's classification. Unfortunately, however, he failed to do so.

Larger divisions of crystals.—Hessel does not refer the thirty-two groups to the usual six (or seven) systems, but united them in four divisions, which he classifies as follows:[14]

I. Class without principal axes (Hauptaxenlos).
    Order 1. With four three-fold axes.
II. Class with a principal axis (Hauptaxig).
    Order 1. Possessing one principal axis.
        Family 1. "One and three dimensional."
        Family 2. "One and two dimensional."
    Order 2. Possessing several different axes. "One and one dimensional."

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[10] Article Krystall, pp. 1062-1157. Reprint, vol. i, pp. 48-145.
[11] Ibid, pp. 1232-1276. Reprint, vol. ii, pp. 45-91.
[12] Reprint, vol. ii, pp. 95-98.
[13] Article Krystall, p. 1280. Reprint, vol. ii, p. 95.
[14] Article Krystall, p. 1277. Reprint, vol. ii, pp. 92-93.

The major divisions are seen to correspond to the isotropic and anisotropic crystals respectively, while the latter are subdivided into the unaxial (order 1), and biaxial (order 2) groups. His four minor divisions thus correspond to the Isometric system, Hexagonal (including Trigonal) system, Tetragonal system, and a fourth division, including the Orthorhombic, Monoclinic, and Triclinic crystals. Hessel shows that these divisions are fundamental, not only geometrically but also physically, and harmonize with the optical and other properties of crystals which he clearly describes.[15]

Hessel's discussion is obscure and very difficult to follow, not only because of its length and involved character, but also because of the many technical terms which he introduces. While his results are of the highest order of importance, they were long forgotten and unappreciated. It is only recently that they have been recognized and estimated at their true worth.[16]

Bravais.—In 1849 A. Bravais published in the Journal de Mathematique a discussion of the subject of symmetrical polyhedra entitled "Memoire sur les Polyhedres de Form Symmetrique.[17]

Bravais was apparently without knowledge of Hessel's previous work, to which he does not refer.

Like Hessel, he endeavors to develop all possible symmetrical polyhedra. This he does by considering symmetry with respect to a center, an axis, or a plane. He develops all possible types of symmetry in four divisions.[18]

I. Asymmetric. Class 1.
II. Symmetric without axis. Classes 2, 3.
III. Symmetric with principal axis.
  Period even. Classes 4-9.
  Period odd. Classes 10-16.
IV. Spheroidal symmetry, no principal axes.
  Quaterternaire.—Forms possessing four-fold axes. Classes 17-21.
  Decemternaire.—Forms possessing ten three-fold axes. Classes 22-23.

He presents a series of theorems concerning all possible combinations of axes, planes, and centers of symmetry, developing finally twenty-three classes of symmetrical polyhedra[19] in the preceding four divisions. Of these the twenty-second and twenty-third classes, containing the decemternaire forms of the above table, develop periods not possible in crystals. There are thus twenty-one classes of symmetry occurring in the four major divisions, which by changes in period develop thirty-one groups of crystals.[20]

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[15] Article Krystall, pp. 1277-1279. Reprint, vol. ii, pp. 93-94.

[16] See article by Sohncke, Zeitschrift für Krystall., bd. 18, pp. 486-498, 1891.

[17] Journal de Mathematique, Pures et Appliquées, vol. 14, 1849, pp. 141-180. Republished in Ostwald's Klassiker der Exakten Wissenschaften, no. 17, 1890.

[18] Journal de Mathematique, vol. 14, 1849, p. 145. Reprint, pp. 12-13.

[19] Ibid., p. 179. Reprint, p. 47.

Bravais' discussion is elegant and simple, but he fails to develop one group, that containing the third order sphenoid of the Tetragonal system. He is concerned with the geometrical qualities of polyhedra rather than their application to crystallography.

Moebius.—A. F. Moebius was engaged in the study of the properties of symmetrical figures at about the time of Bravais' discussion. He published a brief article upon the subject[21] in 1851, in which he promised a full treatment of the question in the future. Although it is stated that his results were largely developed as early as 1852,[22] his more complete discussion was not published during his lifetime, but was issued as a posthumous work, by C. Reinhart, in 1886.[23] Moebius seeks to develop all possible symmetrical figures about a center, a line, or a plane of symmetry, arriving at the following divisions:[24]

I. Forms without axis of symmetry:
    1. Center of symmetry. Symbol O.
    2. Plane of symmetry. Symbol E.
II. Forms possessing a principal axis:
    1. Symmetrical with respect to one axis.
        a. Axis simple. Symbol l_n (n = period of axis).
        b. Axis alternating ("centrirte" axis), a combination of symmetry about an axis and a center of symmetry. Symbol i_n.
    2. Symmetrical with respect to two elements (termed by Moebius "bases") of symmetry:
        a. Possessing two planes of symmetry. Symbol A.
        b. Possessing two axes of symmetry:
            1. Ordinary axis. Symbol B.
            2. Alternating principal axis and lateral axes. Symbol C.
        c. Possessing axes and center of symmetry:
            1. Axis ordinary. Symbol D.
            2. Axis alternating. Symbol D*.

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[20] Bravais uses the following symbols in his table of forms (ibid., p. 144; reprint, p. 12):
C = centers of symmetry.
Λ = principal axis.
L = lateral axes. L = first kind; L′ = second kind.
π = plane of symmetry normal to principal axis.
P = planes parallel to principal axis. P = first kind; P′ = second kind.

[21] Uber das Gesetz der Symmetrie der Krystalle und die Eintheilung der Krystalle in Systeme. Ber. der Königl. Sachs. Gesell. der Wissen., p. 349 (read in 1849).

[22] Moebius: Gesammelte Werke. Herausgeg. von F. Klein. Leipzig, 1886, bd. ii, pp. 564-565.

[23] Theorie der Symmetrischen Figuren. Moebius: Gesammelte Werke, 1886, bd. ii, pp. 563-708.

[24] Ibid., pp. 642-647, where a summary is given of all save first division.

III. Forms possessing several axes of period more than 2:
  1. Tetrahedral forms (p. 653). Symbol T.
  2. Hexahedral forms (p. 664). Symbol H.
  3. Octahedral forms (p. 672). Symbol O.
  4. Dodecahedral forms (p. 679).
  5. Icosahedral forms (p. 692).

All possible groups of crystals are found by substituting the periods 1, 2, 3, 4, 6 in the axes of the above divisions save the last two (Dodecahedral and Icosahedral), which produce no crystallographic groups, since the periods developed are not possible in crystals. In this manner Moebius arrives at twenty-eight groups of crystals only, four of the thirty-two groups being missing. (See table II, p. 396.) His discussion, while clear and simple is therefore incomplete.

Gadolin.—The preceding authors have endeavored to develop all possible forms of symmetrical polyhedra. Alexis Gadolin differed from them in restricting himself to the development of forms possible in crystals. This he did in a memoire published in 1871, entitled "Memoire sur la Deduction d'un Seul Principe de tous les Systems Crystallographiques avec leur Subdivisions."[25] His work possessed such elegance and fullness that it attracted widespread attention to the new conceptions concerning crystallography.

Gadolin first[26] develops all possible forms of symmetry about an axis, or a combination of axes, producing eleven groups of symmetry. He then develops symmetry about combinations of planes with the preceding axes, distinguishing three types.[27] His results may be summarized as follows:

I. Forms possessing axes of symmetry only:
  1. Many axes, 6 groups.
  2. One axis, 4 groups.
  3. No axis, 1 group.

II. Forms possessing axes and planes of symmetry:
  1. Faces parallel, 11 groups.
  2. Faces nonparallel ("Plane of symmetry"), 9 groups.
  3. Alternating ("Sphenoidal") symmetry, 1 group.

Thirty-two groups are shown to be possible in this manner, which are precisely the groups developed by Hessel. Gadolin next refers these groups[28] to the ordinary six systems of crystals, classifying the groups as holohedral, hemihedral, hemimorphic, and tetratohedral. The entire discussion is based upon the law of the Rationality of Parameters, to which he devotes especial attention in an appendix.[29]

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[25] Acta Societatis Scientiarum Fennicæ Helsingforsiæ, vol. 19, 1871, pp. 1-71 (read in 1867). Reprinted in Ostwald's "Klassiker der Exakten Wissenschaften," no. 75, 1896.

[26] Ibid., pp. 11-15. Reprint, pp. 12-18.

[27] Ibid., pp. 16-25. Reprint, pp. 19-31.

[28] Ibid., pp. 25-41. Reprint, pp. 31-49.

[29] Ibid., Appendix A.

Gadolin's discussion is so full and clear that for a time the origination of the entire conception of the thirty-two groups of crystals seems to have been attributed to him rather than to Hessel, whose work was generally neglected. While superior to Hessel in clearness and brevity, his work is much less extended. Moreover, he does not call attention either to the seven types of axes or to the large and philosophical grouping of that author.

Curie.—In the year 1884 P. Curie published two papers[30] in the Bulletin of the Mineralogical Society of France upon symmetrical figures.

Curie develops all possible forms of symmetrical figures, of which he recognizes nine types and twenty-four subtypes.[31] He then considers the possible crystallographic forms which possess the periods 1, 2, 3, 4, 6. He finds that they are restricted to five of his types and eleven subtypes shown in the following table:[32]

III. Cubic (Isometric).
    1. No planes of symmetry.
    2. Planes of symmetry.
IV. Tetrahedral (Isometric).
    1. No planes of symmetry.
    2. Planes and axes of symmetry coincident.
    3. Planes and axes of symmetry alternate.
V. Forms possessing a double principal axis (that is, containing many axes).
    1. No planes of symmetry.
    2. Planes and axes of symmetry coincident.
    3. Planes and axes of symmetry alternate.
VI. Forms possessing an inverse axis (that is, containing one axis only).
    1. No planes of symmetry.
    2. Planes of symmetry normal to axis.
    3. Alternating planes of symmetry normal to axis.
    4. Planes of symmetry parallel to axis.
IX. Forms possessing no repetition (that is, containing no axis).
    1. No axis.
    2. Center of symmetry.
    3. Plane of symmetry.

The different periods of the axes of symmetry in the above divisions give rise to thirty-two groups of symmetry possible in crystals, which are precisely the same as those found by the earlier investigators.

Curie's discussion is devoted to the geometric rather than to the crystallographic aspects of the subject. He calls attention to the fact that one group (the Tetragonal trisphenoidal group) is missing in Bravais' table.[33]

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[30] Sur les questions d'ordre. Bulletin de la Société Mineralogie de France, vol. 7, 1884, pp. 89-118.
Sur la Symetrie, ibid., pp. 418-457.

[31] Ibid., p. 450, where a table is given.

[32] Bulletin de la Société Mineralogie de France, table, p. 450. The subdivisions are found in the discussion, pp. 444-449.

Fedorow.—Fedorow contributed a highly important discussion in 1885, entitled "Elementen der Lehren von den Figuren."[34] His work, unfortunately, is in the Russian language, so that it did not at once gain the wide attention of which it was worthy.

Fedorow gives a brief outline of his results in an article published in Zeitschrift für Kryst. in 1892.[35] He states that his results are almost identical with those of Schoenflies, though obtained by different methods. He develops the thirty-two crystal groups in four major divisions, as follows:[36]

I. With principal axis.
    1. Hexagonal and Trigonal divisions.
    2. Tetragonal division.
    3. Division possessing two- and one-fold periods (including Orthorhombic, Monoclinic, and Triclinic systems).
II. Without principal axis (Isometric).

The subdivisions of these types are shown in table II, page 396.

Fedorow introduces the conception of a combined axis and plane of symmetry (zusammengesetzte symmetrie) to produce the type of crystals frequently termed sphenoidal (alternating).

Minnigerode.—B. Minnigerode discussed all possible symmetrical figures in a brief article in the Neues Jahrbuch for 1887.[37] He develops symmetrical assemblages, which he terms groups, by the method of determinants, and finally restricts the forms arrived at to those possessing the periods possible in crystals. The divisions of crystals found by him are the following:[38]

I. Derivatives of Octohedral group (Isometric system). Groups 1-5.
II. Derivatives of Dihedral group.
    1. Possessing six- or three-fold period (Hexagonal system).
        a. Six-fold axis. Groups 6-10.
        b. Three-fold axis and center of symmetry = six-fold period. Groups 11-12.
        c. Three-fold axis and center of symmetry = three-fold period. Groups 13-17.
    2. Possessing four-fold period, or two-fold period and center of symmetry = four-fold period (Tetragonal system).
        a. Four-fold period. Groups 18-22.

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[33] Ibid., p. 454.

[34] St. Petersburg, 1885.

[35] Vol. 20, 1892, pp. 25-75.

[36] See synopsis by Schoenflies, Krystall Systeme und Krystall Structur, 1891, p. 104.

[37] Untersuchung über die symmetrische Verhältnisse der Krystalle. Neues Jahrb. für Min. Geol. und Pal. Beilage, bd. v, 1887, pp. 145-166.

[38] Ibid., pp. 157-164.

    - *b.* Two-fold period and center of symmetry = four-fold period. Groups 23-24.
3. Possessing two-fold period, with or without center of symmetry = two-fold period or without axis of symmetry.
    - *a.* Orthorhombic. Groups 25-27.
    - *b.* Monoclinic. Groups 28-30.
    - *c.* Triclinic. Groups 31-32.

Thirty-two groups of crystals are obtained by employing the periods possible in crystals.

Minnigerode's results, though obtained by an independent method, coincide fully with those of the preceding workers. His discussion, while highly mathematical, is elegant and brief.

Schoenflies.—In the year 1891 A. Schoenflies published the most important contribution to the classification of crystals (save perhaps that of Fedorow) since the memoire of Gadolin. His work, entitled "Krystall Systeme and Krystall Structure,"[39] is devoted to the discussion of the geometrical form and inner structure of crystals.

Like Gadolin, he restricts his discussion to the forms possible in crystals under the law of the Rationality of Parameters. He recognizes symmetry of two kinds:[40]

A. Symmetry by rotation, which he terms symmetry of the first kind.

B. Symmetry by reflection (variously combined with rotation), termed symmetry of the second kind.

Forms of the first kind possess an axis of symmetry only. Forms of the second kind are produced by passing planes in various positions through the axes of the first kind. The following table[41] shows his divisions:

I. Possessing axes of symmetry only.	II. Possessing planes combined with axes of symmetry.		
1. No axis. Identity. C_1.			
2. One axis. *Cyclic.* C_n.	*Cyclic*.......	Plane horizontal. Plane vertical.	C^h. C^v.
3. Several axes, one principal. Period 2, *Vierer.* V.	*Vierer*	Plane horizontal. Plane diagonal.	V^h. V^d.
Period over 2, *Dihedral.* D_n.	*Dihedral*	Plane horizontal. Plane diagonal.	D^h. D^d.
4. Several axes of period over 2.			
Period 2, *Tetrahedral.* T.	*Tetrahedral*..	Plane horizontal. Plane diagonal.	T^h. T^d.
Period 4, *Octahedral.* O.	*Octahedral* ..	Plane horizontal.	O^h.

These divisions develop thirty-two groups of symmetry by changes in the periods of the axes.

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[39] Leipzig, 1891. See an excellent brief synopsis of his results in G. H. Williams' Crystallography, third edition, 1892, pp. 183-195.

[40] Ibid., p. 129.

[41] Ibid., pp. 74, 102.

Schoenflies proposes a two-fold classification of the thirty-two groups so developed:[42]

I. Into divisions based on the period and character of the principal axis of symmetry comprising Isometric, Hexagonal, Tetragonal, Trigonal, Digonal, and Monogonal divisions.

II. Into the ordinarily accepted seven systems, essentially as in the classification of Gadolin. His work, which is of great importance, closes with a highly suggestive discussion of the inner structure of crystals.

Miers.—It remains to make reference to the classification introduced by H. A. Miers in the year 1902 in his work on Mineralogy.[43] He recognizes the close relations which exist among a number of the groups of crystals, giving them analogous names. He classifies a large number of the groups into the four divisions recognized by Hessel and designates them in a somewhat analogous manner, prefixing the syllable di (double = Hessel's zweifach) to the name of the system for groups having crystal faces in pairs. He does not, however, apply the same classification to all systems of crystals. His divisions are exhibited in the following table,[44] in which the larger grouping is numbered and arranged by the writer. Miers does not present the larger grouping here given.

I. No axis of symmetry.
  1. Asymmetric.
  2. Center of symmetry.
  3. Plane of symmetry.
II. Possessing a principal axis of symmetry.
  1. Polar (hemimorphic) { Single.
      Double (di).
  2. Alternating { Single.
      Double (di).
  3. Holoaxial (many axes) { Single.
  4. Equatorial (horizontal plane of symmetry) { Single.
      Double (di).
III. With equal axes (Isometric).
  1. Polar (hemimorphic three-fold axes) { Single.
      Double (di).
  2. Holoaxial (many axes, four-fold) { Single.
  3. Central (center of symmetry) { Single.
      Double (di).

RELATION OF THE DIVISIONS PROPOSED TO THOSE OF PRECEDING AUTHORS

The relation of the author's results to those obtained by the various investigators is shown in the following tables, the first giving the larger divisions and the second the subordinate groups as developed by the different authors:

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[42] Ibid., pp. 110, 125-131.

[43] Mineralogy. MacMillan and Company, 1902.

[44] Ibid., p. 280.

TABLE I—*Larger Divisions of Crystals*

Hessel, 1830	Bravias, 1849	Moebius, 1851 (1886)	Gadolin, 1871	Curie, 1884
I. Without a principal axis (Isometric). II. With a principal axis. 1. Axis unlike ended (*u*). 2. Axes like ended. *a*. Forms opposite (*G*). *b*. Forms alternate (*g*). *c*. Forms oblique (*e*). The principal axes of all save last are simple and double.	I. Asymmetric. II. Symmetric without principal axis. III. Symmetric with principal axis. 1. Period even. 2. Period odd. IV. Spheroidal symmetry. 1. Four three-fold axes.	I. Without axis of symmetry. II. With principal axis. 1. One axis only. 2. Two bases of symmetry. *a*. Two planes. *b*. Two axes. *c*. Axis and center III. Several axes of period more than two.	I. Axes only. 1. Many axes. 2. One axis. 3. No axis. II. Planes and axes. 1. Faces parallel. 2. Faces not parallel. 3. Alternating (spheroidal) symmetry.	III. Cubic. IV. Tetrahedral. V. Double principal axes (that is, many axes). VI. Inverse axis (that is, one axis). IX. No repetition (that is, no axis). Subdivisions based upon presence and position of planes of symmetry.
Fedorow, 1885	Minnigerode, 1887	Schoenflies, 1891	Miers, 1902	Swartz, 1909
I. With principal axis. 1. Period, six or three fold. 2. Period, four fold. 3. Period, two or one fold. II. With equal axes (Isometric).	I. Octahedral (Isometric). II. Dihedral. 1. Period, six or three fold. 2. Period, four fold. 3. Period, two or one fold. Developed by means of determinants.	I. Axes only. 1. Identity. 2. One axis. 3. Several axes—one principal. 4. Several axes of period more than two (Isometric). II. Planes and axes. Planes are passed through preceding axes yielding corresponding groups.	I. No axes of symmetry. II. Principal axis. 1. Polar (hemimorphic) 2. Alternate. 3. Holoaxial (many axes). 4. Equatorial (horizontal plane). III. Equal axes (Isometric). 1. Polar. 2. Holoaxial. 3. Central (center of symmetry). All subdivisions save holoaxial yield "di" (double) forms.	I. Symmetry by rotation. 1. One axis. Axial. 2. Many axes. Polyaxial. II. Symmetry by reflection. A. One axis with— 3. Normal plane. Orthoaxial. 4. Parallel plane. Hedral. B. Many axes with— 5. Coinciding planes. Orthohedral. 6. Alternating planes. Amebahedral. III. Combined rotation and reflection. 7. Alternating axis. Amebaxial.

TABLE II—*Groups of Crystals*

	Axial					Orthoaxial				Polyaxial						Amebaxial		
										Singular axis				No sing. axis				
Period of axes..	1	2	3	4	6	2	3	4	6	2	3	4	6	2	4	2	4	6
Hessel..............	$1^1 u^1$	$1^1 u^2$	$1^1 u^3$	$1^1 u^4$	$1^1 u^6$	$1^1 G^2$	$1^1 G^3$	$1^1 G^4$	$1^1 G^6$	$1^1 e^2$	$1^1 e^3$	$1^1 e^4$	$1^1 e^6$	$4^1 u^3$	$4^1 e^3$	$1^1 g^1$	$1^1 g^2$	$1^1 g^3$
Bravais............	I.1	$III.4_2$	$III.10_3$	$III.4_4$	$III.4_6$	$III.5_2$	$III.12_3$	$III.5_4$	$III.5_6$	$III\ 6_2$	$III.13_3$	$III.6_4$	$III.6_6$	IV.17	IV.20	II.2	—	$III.11_3$
Moebius............	—	l_2	l_3	l_4	l_6	D_2	i_3	D_4	D_6	B_2	B_3	B_4	B_6	T.	$O_1=H_1$	O.	i_2	i_3
Gadolin............	I 3.1	I 2.4	I 2.3	I 2.2	I 2.1	II 1.6	II 2.8	II 1.4	II 1.8	I 1.4	I 1.5	I 1.3	I 1.1	I 1.6	I 1.2	II 1.11	II 3.	II 1.10
Curie	IX 1.	VI 1.2	VI 1.3	VI 1.4	VI 1.6	VI 2.2	VI 2.3	VI 2.4	VI 2.6	V 1.2	V 1.3	V 1.4	V 1.6	IV 1.	III 1.	IX 3.	VI 3.2	VI 3.3
Fedorow.	I 3.8	I 3.6	I 1.12	I 2.7	I 1.7	I 3.2	I 1.10	I 2.4	I 1.4	I 3.3	I 1.9	I 2.3	I 1.3	II, §42	II, §41	I 3.4	I 2.5	I 1.5
Minnigerode.....	I 3.32	I 3.29	I 1.17	I 2.22	I 1.10	I 3.28	I 1.12	I 2.21	I 1.9	I 3.27	I 1.15	I 2.20	I 1.8	II.5	II.3	I 3.31	I 2.24	I 1.16
Schoenflies	C_1	C_2	C_3	C_4	C_6	C^h_2	C^h_3	C^h_4	C^h_6	V	D_3	D_4	D_6	T	O	S_2	S_4	S_6
Miers.	I 1.	II p_2	II p_3	II p_4	II p_6	II e_2	II e_3	II e_4	II e_6	II h_2	II h_3	II h_4	II h_6	III p	III h	I 2.	II a_4	II a_6
Groth................	.1	.3	.16	.10	.23	.5	.19	.13	.25	.6	.18	.12	.24	.28	.29	.2	.9	.17

	Hedral					Orthohedral										Amebahedral		
						Singular axis				No singular axis						Singular axis		No singular axis
Period of axes..	1	2	3	4	6	2	3	4	6	2	4					4	6	4
Hessel..............	$1^2 u^1$	$1^2 u^2$	$1^2 u^3$	$1^2 u^4$	$1^2 u^6$	$1^2 G^2$	$1^2 G^3$	$1^2 G^4$	$1^2 G^6$	$4^2 g^3$	$4^1 g^2$	....	....	....	....	$1^2 g^2$	$1^2 g^3$	$4^2 u^3$
Bravais	II.3	$III.7_2$	$III.14_3$	$III.7_4$	$III.7_6$	$III.8_2$	$III.16_3$	$III.8_4$	$III.8_6$	IV.21	IV.18	....	....	....	....	$III.9_2$	$III.15_3$	IV.19
Moebius..	E.	A_2	A_3	A_4	A_6	—	C_3	—	—	O_2	H_2	....	....	....	....	C_4	C_6	T_2
Gadolin	II 2.5	II 2.4	II 2.9	II 2.2	II 2.7	II 1.5	II 2.6	II 1.3	II 1.7	II 1.6	II 1.1	....	....	....	....	II 2.3	II 1.9	II 2.1
Curie................	IX 2	VI 4.2	VI 4.3	VI 4.4	VI 4.6	V 2.2	V 2.3	V 2.4	V 2.6	III 2.	IV 2.	....	....	....	....	V 3.2	V 3.3	IV 3.
Fedorow.	I 3.7	I 3.5	I 1.11	I 2.6	I 1.6	I 3.1	I 1.8	I 2.1	I 1.1	II §38	II §40	....	....	....	....	I 2.2	I 1.2	II §39
Minnigerode.....	I 3.30	I 3.26	I 1.14	I 2.19	I 1.7	I 3.25	I 1.11	I 2.18	I 1.6	II.1	II.4	....	....	....	....	I 2.23	I 1.13	II.2
Schoenflies	S	C^v_2	C^v_3	C^v_4	C^v_6	V^h	D^h_3	D^h_4	D^h_6	O^h	T^h	....	....	....	....	V^d	D^d_3	T^d
Miers	I 3.	II^2 p_2	II^2 p_3	II^2 p_4	II^2 p_6	II^2 e_2	II^2 e_3	II^2 e_4	II^2 e_6	III c	III^2 c	....	....	....	....	II^2 a_4	II^2 a_6	III^2p
Groth....	.4	.7	.20	.14	.26	.8	.22	.15	.27	.30	.32	....	....	....	....	.11	.21	.31

Notes on Table II.[45]

Unless otherwise stated, the formulæ preceding the period (.) indicate the divisions given in the foregoing discussion, which are summarized in table I. The number following the period shows the author's number of the group. Letters are used when the author has so employed them. § indicates section in which the group is discussed.

Hessel.—The letters indicate character of chief axis; for example, u = ungleichendig, etcetera. The large number shows number of such axes; the first small number indicates whether axis is single (1) or double (2); the second small number shows period of the axis. This $1^2 G^2$ signifies one double axis, gleichstellig, 2-fold.[46]

Miers.—Letter signifies division; for example, p = polar; a = alternate, etcetera. Small figure 2 signifies double (di) form.

Groth.—Numbers indicate group. Physikalische Krystallographie, 4th edition, 1895, pp. 329-331.

SUMMARY

The purpose of the preceding discussion is to point out the existence of certain natural and well defined types of symmetry in crystals, and to present a development of the thirty-two groups which is adapted to the use of elementary students and which emphasizes simple and natural relations of crystals springing from the existence of these types. The subject is treated in two parts.

Part I contains the discussion of the classification proposed by the author.

1. An elementary development of the thirty-two groups is given, by which it is shown that all crystals fall into seven fundamental classes of symmetry.
2. The seven classes are named, the characteristics of each are discussed, and the term class defined.
3. The various classes and groups are referred to the accepted systems.
4. It is shown that this development expresses the larger relations and harmonizes with the fundamental physical properties of crystals.

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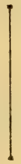
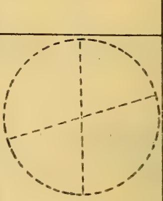
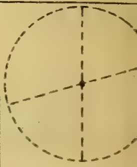
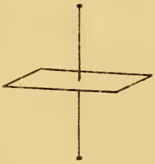
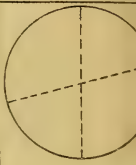
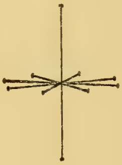
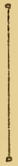
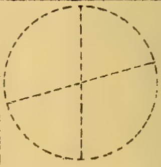
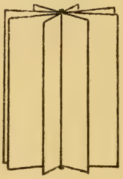
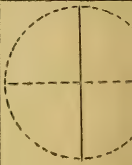
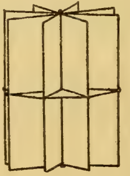
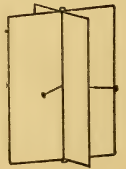
[45] This table is based in part on a similar table of Schoenflies, "Krystall Systeme und Krystall Structur," 1901, table iii, p. 104.

[46] These formulæ were first used by Hessel in a later publication, "Ueber gewisse merkwürdige statische und mechanische Eigenschaften des Raumes," Marburg, 1862. Universitätsschrift.

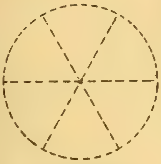
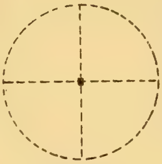
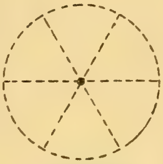
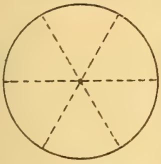
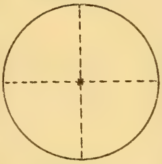
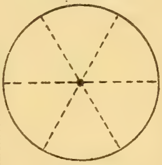
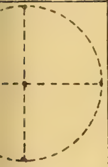
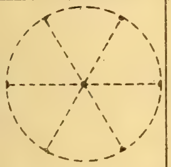
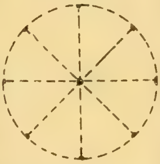
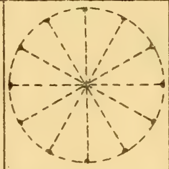
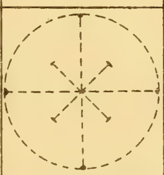
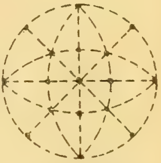
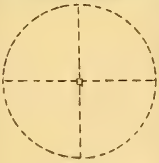
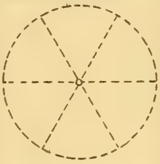
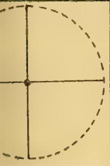
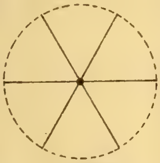
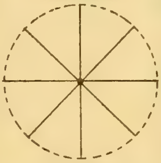
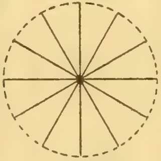
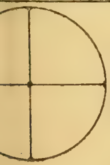
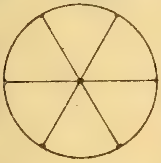
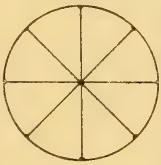
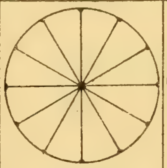
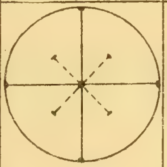
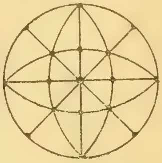
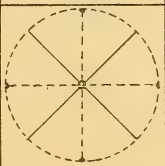
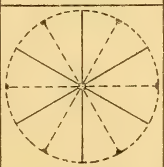
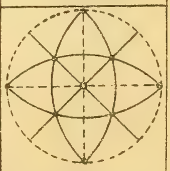
5. Certain inferences springing from the preceding discussion are considered.

6. The advantages which are believed to be presented by this method of development are briefly summarized.

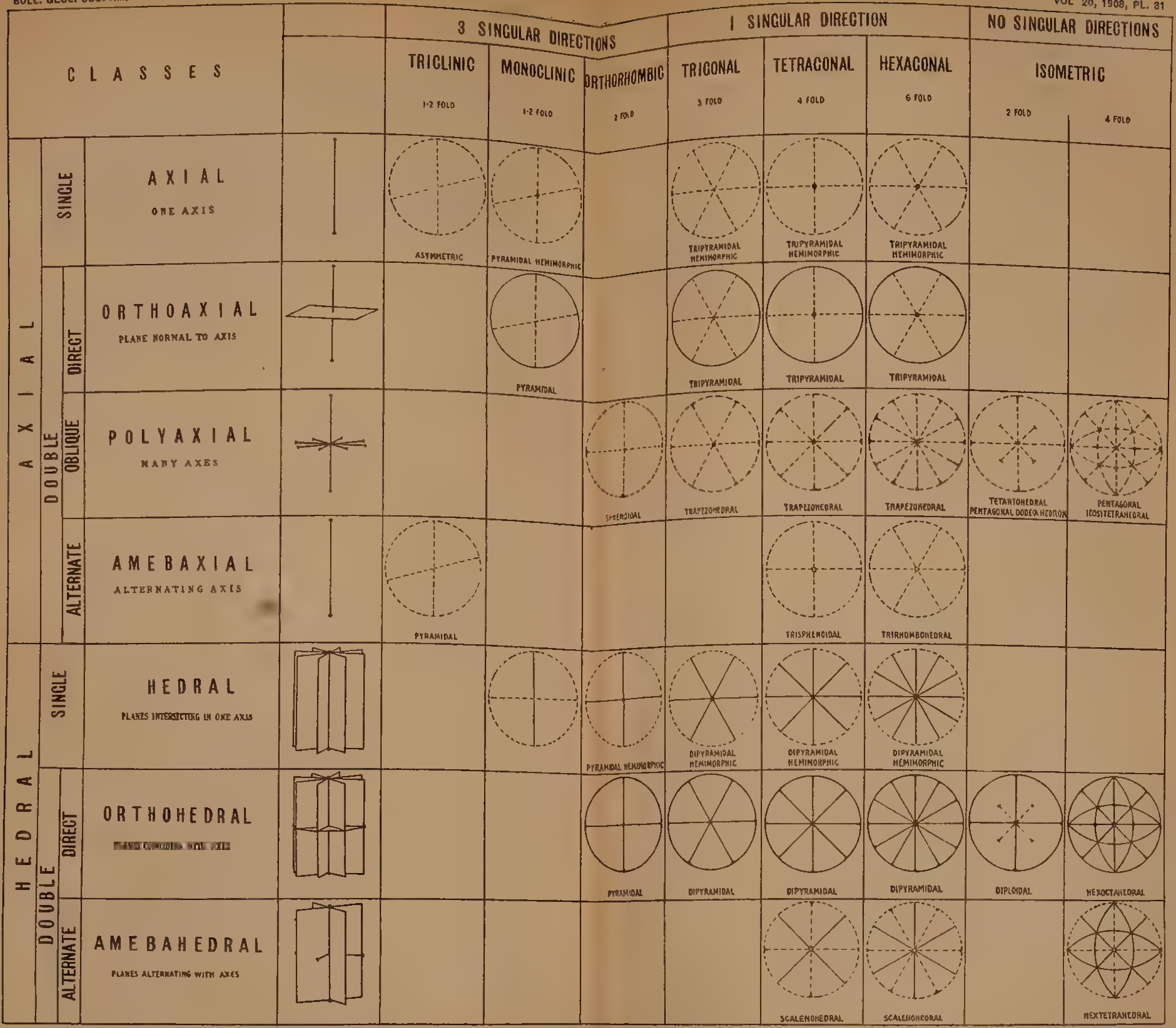
Part II contains a brief historical review of the development of the modern classification of crystals and shows the relation of the author's divisions to those of previous investigators.

CLASSES					3 SINGULAR DIRE	
					TRICLINIC 1-2 FOLD	MONOCLINIC 1-2 FOLD
AXIAL	SINGLE		AXIAL ONE AXIS		 ASYMMETRIC	 PYRAMIDAL HEMIMORP
	DOUBLE	DIRECT	ORTHOAXIAL PLANE NORMAL TO AXIS			 PYRAMIDAL
		OBLIQUE	POLYAXIAL MANY AXES			
		ALTERNATE	AMEBAXIAL ALTERNATING AXIS		 PYRAMIDAL	
HEDRAL	SINGLE		HEDRAL PLANES INTERSECTING IN ONE AXIS			
	DOUBLE	DIRECT	ORTHOHEDRAL PLANES COINCIDING WITH AXES			
		ALTERNATE	AMEBAHEDRAL PLANES ALTERNATING WITH AXES			

CLASS

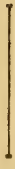
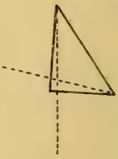
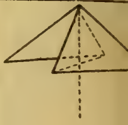
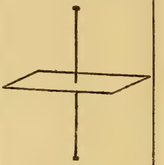
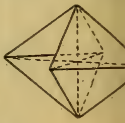
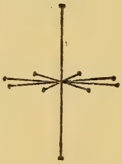
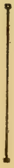
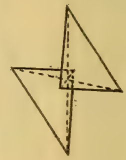
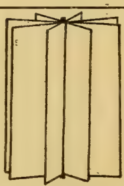
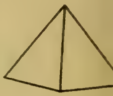
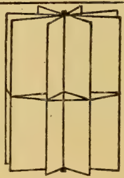
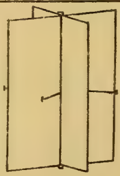
	I SINGULAR DIRECTION			NO SINGULAR DIRECTIONS	
RHOMBIC	TRIGONAL	TETRAGONAL	HEXAGONAL	ISOMETRIC	
2 FOLD	3 FOLD	4 FOLD	6 FOLD	2 FOLD	4 FOLD
	 TRIPYRAMIDAL HEMIMORPHIC	 TRIPYRAMIDAL HEMIMORPHIC	 TRIPYRAMIDAL HEMIMORPHIC		
	 TRIPYRAMIDAL	 TRIPYRAMIDAL	 TRIPYRAMIDAL		
 HENOIDAL	 TRAPEZOHEDRAL	 TRAPEZOHEDRAL	 TRAPEZOHEDRAL	 TETARTOHEDRAL PENTAGONAL DODECAHEDRON	 PENTAGONAL ICOSITETRAHEDRAL
		 TRISPHENOIDAL	 TRIRHOMBOHEDRAL		
 DAL HEMIMORPHIC	 DIPYRAMIDAL HEMIMORPHIC	 DIPYRAMIDAL HEMIMORPHIC	 DIPYRAMIDAL HEMIMORPHIC		
 PYRAMIDAL	 DIPYRAMIDAL	 DIPYRAMIDAL	 DIPYRAMIDAL	 DIPLOIDAL	 HEXOCTAHEDRAL
		 SCALENOHEDRAL	 SCALENOHEDRAL		 HEXTETRAHEDRAL

YSTALS

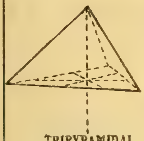
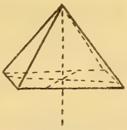
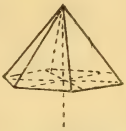
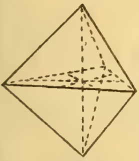
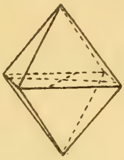
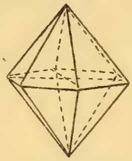
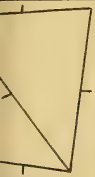
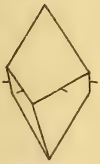
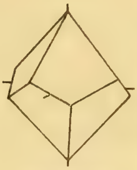
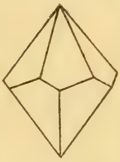
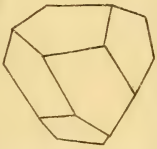
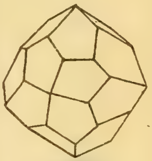
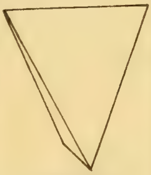
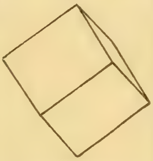
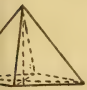
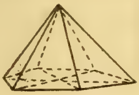
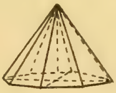
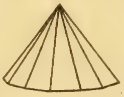
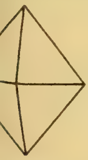
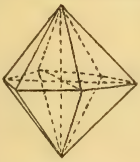
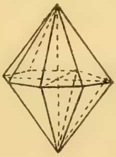
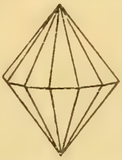
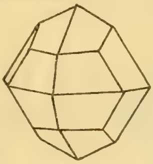
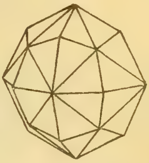
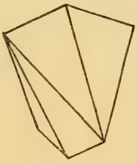
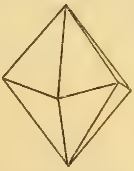
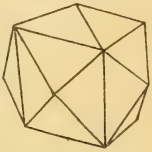


CLASSES					3 SINGULAR DIRECTIONS			1 SINGULAR DIRECTION			NO SINGULAR DIRECTIONS	
					TRICLINIC 1-2 FOLD	MONOCLINIC 1-2 FOLD	ORTHORHOMBIC 2 FOLD	TRIGONAL 3 FOLD	TETRAGONAL 4 FOLD	HEXAGONAL 6 FOLD	ISOMETRIC 2 FOLD	ISOMETRIC 4 FOLD
AXIAL	SINGLE		AXIAL ONE AXIS		ASYMMETRIC	PYRAMIDAL HEMIMORPHIC		TRIPYRAMIDAL HEMIMORPHIC	TRIPYRAMIDAL HEMIMORPHIC	TRIPYRAMIDAL HEMIMORPHIC		
	DOUBLE	DIRECT	ORTHOAXIAL PLANE NORMAL TO AXIS			PYRAMIDAL		TRIPYRAMIDAL	TRIPYRAMIDAL	TRIPYRAMIDAL		
		OBLIQUE	POLYAXIAL MANY AXES				SPHENOIDAL	TRAPEZOHEDRAL	TRAPEZOHEDRAL	TRAPEZOHEDRAL	TETARTOHEDRAL PENTAGONAL DODECAHEDRON	PENTAGONAL ICOSITETRAHEDRAL
		ALTERNATE	AMEBAXIAL ALTERNATING AXIS		PYRAMIDAL				TRISPHENOIDAL	TRIRHOMBOHEDRAL		
HEDRAL	SINGLE		HEDRAL PLANES INTERSECTING IN ONE AXIS				PYRAMIDAL HEMIMORPHIC	DIPYRAMIDAL HEMIMORPHIC	DIPYRAMIDAL HEMIMORPHIC	DIPYRAMIDAL HEMIMORPHIC		
	DOUBLE	DIRECT	ORTHOHEDRAL PLANES COINCIDING WITH AXES				PYRAMIDAL	DIPYRAMIDAL	DIPYRAMIDAL	DIPYRAMIDAL	DIPLOIDAL	HEXOCTAHEDRAL
		ALTERNATE	AMEBAHEDRAL PLANES ALTERNATING WITH AXES						SCALENOHEDRAL	SCALENOHEDRAL		HEXTETRAHEDRAL

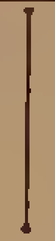
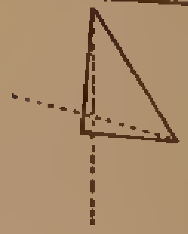
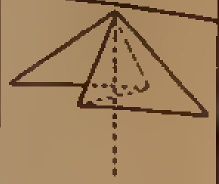
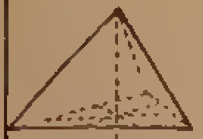
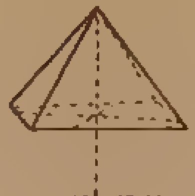
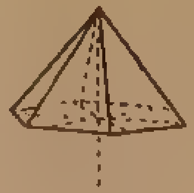
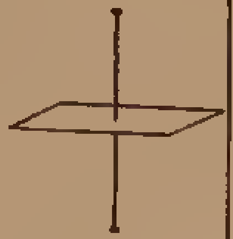
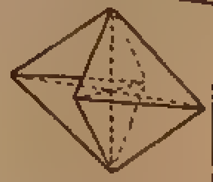
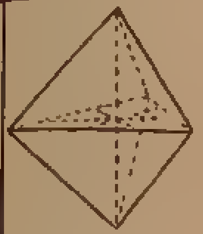
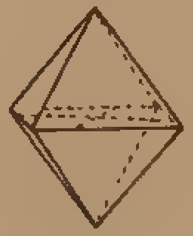
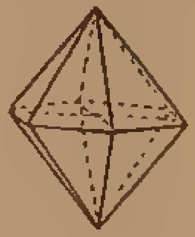
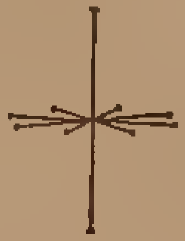
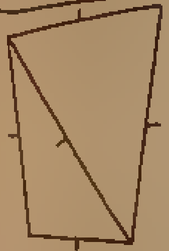
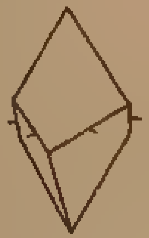
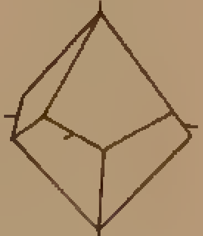
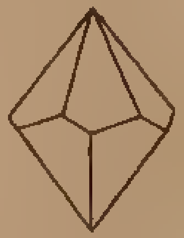
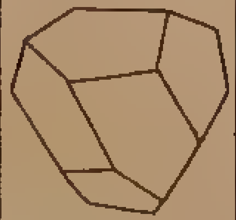
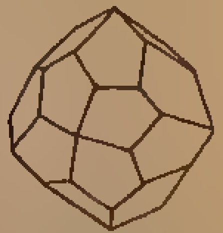
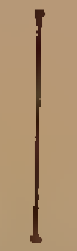
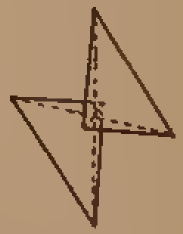
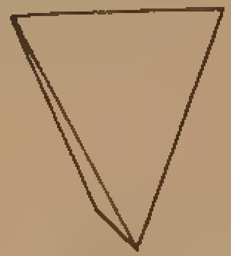
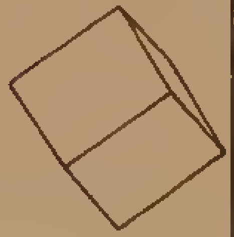
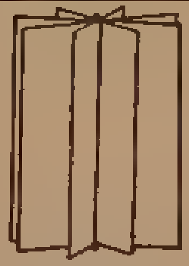
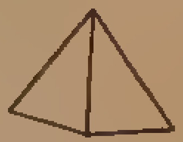
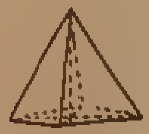
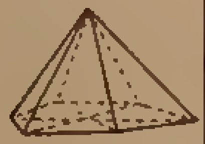
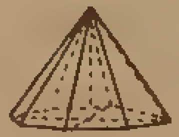
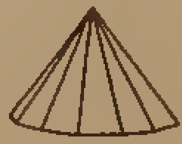
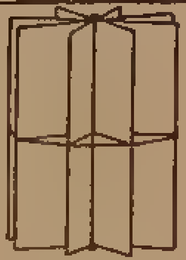
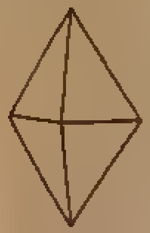
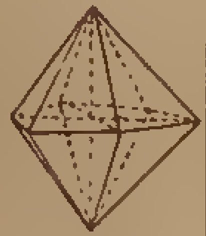
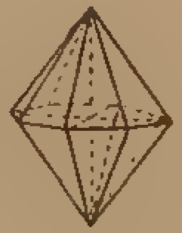
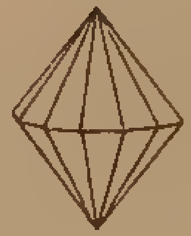
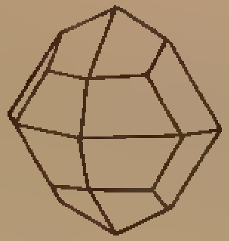
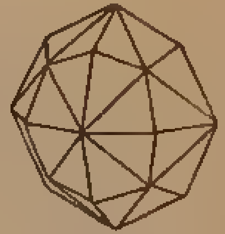
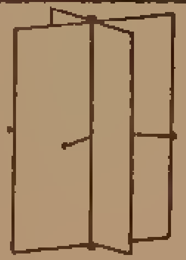
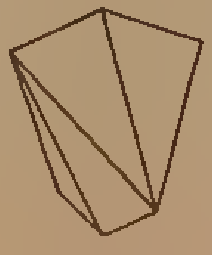
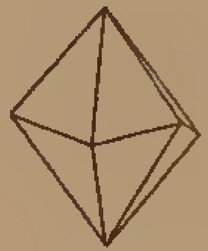
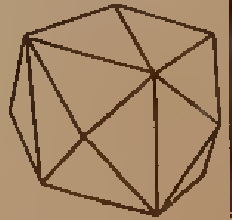
CLASSES OF CRYSTALS

					3 SINGULAR DIR	
CLASSES					TRICLINIC 1-2 FOLD	MONOCLINI 1-2 FOLD
AXIAL	SINGLE		AXIAL ONE AXIS		 ASYMMETRIC	 PYRAMIDAL HEMIMOR
	DOUBLE	DIRECT	ORTHOAXIAL PLANE NORMAL TO AXIS			 PYRAMIDAL
		OBLIQUE	POLYAXIAL MANY AXES			
		ALTERNATE	AMEBAXIAL ALTERNATING AXES		 PYRAMIDAL	
HEDRAL	SINGLE		HEDRAL PLANES INTERSECTING IN ONE AXIS			
	DOUBLE	DIRECT	ORTHOHEDRAL PLANES COINCIDING WITH AXES			
		ALTERNATE	AMEBAHEDRAL PLANES ALTERNATING WITH AXES			

CLASSE

	I SINGULAR DIRECTION			NO SINGULAR DIRECTIONS	
RHOMBIC	TRIGONAL	TETRAGONAL	HEXAGONAL	ISOMETRIC	
FOLD	3 FOLD	4 FOLD	6 FOLD	2 FOLD	4 FOLD
	 TRIPYRAMIDAL HEMIMORPHIC	 TRIPYRAMIDAL HEMIMORPHIC	 TRIPYRAMIDAL HEMIMORPHIC		
	 TRIPYRAMIDAL	 TRIPYRAMIDAL	 TRIPYRAMIDAL		
 HENOIDAL	 TRAPEZOHEDRAL	 TRAPEZOHEDRAL	 TRAPEZOHEDRAL	 TETARTOHEDRAL PENTAGONAL DODECAHEDRON	 PENTAGONAL ICOSITETRAHEDRAL
		 TRISPHENOIDAL	 TRIRHOMBOHEDRAL		
 AL HEMIMORPHIC	 DIPYRAMIDAL HEMIMORPHIC	 DIPYRAMIDAL HEMIMORPHIC	 DIPYRAMIDAL HEMIMORPHIC		
 YRAMIDAL	 DIPYRAMIDAL	 DIPYRAMIDAL	 DIPYRAMIDAL	 DIPLOIDAL	 HEXOCTAHEDRAL
		 SCALENOHEDRAL	 SCALENOHEDRAL		 HEXTETRAHEDRAL

STALS

					3 SINGULAR DIRECTIONS			1 SINGULAR DIRECTION			NO SINGULAR DIRECTIONS	
			CLASSES		TRICLINIC 1-2 FOLD,	MONOCLINIC 1-2 FOLD	ORTHORHOMBIC 2 FOLD	TRIGONAL 3 FOLD	TETRAGONAL 4 FOLD	HEXAGONAL 6 FOLD	ISOMETRIC 2 FOLD	ISOMETRIC 4 FOLD
AXIAL	SINGLE		**AXIAL** ONE AXIS		 ASYMMETRIC	 PYRAMIDAL HEMIMORPHIC		 TRIPYRAMIDAL HEMIMORPHIC	 TRIPYRAMIDAL HEMIMORPHIC	 TRIPYRAMIDAL HEMIMORPHIC		
	DOUBLE	DIRECT	**ORTHOAXIAL** PLANE NORMAL TO AXIS			 PYRAMIDAL		 TRIPYRAMIDAL	 TRIPYRAMIDAL	 TRIPYRAMIDAL		
		OBLIQUE	**POLYAXIAL** MANY AXES				 SPHENOIDAL	 TRAPEZOHEDRAL	 TRAPEZOHEDRAL	 TRAPEZOHEDRAL	 TETARTOHEDRAL PENTAGONAL DODECAHEDRON	 PENTAGONAL ICOSITETRAHEDRAL
		ALTERNATE	**AMEBAXIAL** ALTERNATING AXES		 PYRAMIDAL				 TRISPHENOIDAL	 TRIRHOMBOHEDRAL		
HEDRAL	SINGLE		**HEDRAL** PLANES INTERSECTING IN ONE AXIS				 PYRAMIDAL HEMIMORPHIC	 DIPYRAMIDAL HEMIMORPHIC	 DIPYRAMIDAL HEMIMORPHIC	 DIPYRAMIDAL HEMIMORPHIC		
	DOUBLE	DIRECT	**ORTHOHEDRAL** PLANES COINCIDING WITH AXES				 PYRAMIDAL	 DIPYRAMIDAL	 DIPYRAMIDAL	 DIPYRAMIDAL	 DIPLOIDAL	 HEXOCTAHEDRAL
		ALTERNATE	**AMEBAHEDRAL** PLANES ALTERNATING WITH AXES						 SCALENOHEDRAL	 SCALENOHEDRAL		 HEXTETRAHEDRAL

CLASSES OF CRYSTALS

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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AFTONIAN SANDS AND GRAVELS IN WESTERN IOWA[1]

BY B. SHIMEK

(Presented by title before the Society December 31, 1908)

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INTRODUCTION

The term Aftonian was first applied by Chamberlin[2] to interglacial beds of gravel and peat near Afton Junction, Iowa, under the impression that they were later than the Kansan. The first correct reference of the Aftonian to its place below the Kansan was subsequently made by Chamberlin[3] after a reexamination of the type locality.

PREVIOUSLY KNOWN DISTRIBUTION OF AFTONIAN BEDS IN IOWA

PEAT

Subsequent investigations by members of the staff of the Iowa Geological Survey have shown that the Aftonian is widely distributed in the state. Peat beds belonging to this stage have been reported from Oelwein, in Fayette county;[4] from Scott county (doubtfully);[5] from Cedar county (doubtfully);[6] from Tama county;[7] from Chickasaw county;[8] from Union county,[9] and several additional probable localities in southern Iowa are given by Bain.[10] Four species of mosses (*Hypnum*)[11] and the wood of a conifer (*Larix*)[12] have been reported from these peat beds.

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[1] Received by the Secretary of the Society December 31, 1908.
[2] Geikie: "Great Ice Age," 1894, pp. 773-774; Journal of Geology, vol. iii, 1895, p. 272.
[3] Journal of Geology, vol. iv, 1896, pp. 873-874.

SAND AND GRAVEL

Gravel and sand beds belonging to this stage have also been noted in the Reports of the Iowa Geological Survey from the following counties: Marshall,[13] Muscatine,[14] Louisa,[15] Webster,[16] Benton,[17] Ida and Sac,[18] and in other publications from the type locality in Union county.[19] It will be observed that thus far no gravels from the western part of the state have been definitely referred to the Aftonian.

THE AFTONIAN IN WESTERN IOWA

While engaged in the survey of Harrison and Monona counties for the Iowa Geological Survey the writer found numerous deposits of sands and gravels clearly belonging to the Aftonian stage.[20] At a number of points in these and neighboring counties sand and gravel pits have been operated for several years in connection with cement block and tile plants, or for building purposes, but the deposits were regarded as local pockets.

PREVIOUS WORK IN WESTERN IOWA

The geologists who have studied the neighboring counties in recent years found like deposits of sand and gravel, and regarded them as lacus-

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[4] By Finch, Beyer, Macbride, and Calvin, in Proceedings of the Iowa Academy of Sciences, vol. iv, 1897, pp. 54-68; T. E. Savage: Reports of the Iowa Geological Survey, vol. xv, 1905, p. 523.

[5] By W. H. Norton, ibid., vol. ix, 1897, p. 474.

[6] By W. H. Norton, ibid., vol. xi, 1899, p. 343.

[7] By T. E. Savage, ibid., vol. xiii, 1903, pp. 232-233.

[8] By S. Calvin, ibid., vol. xiii, 1903, p. 291.

[9] T. C. Chamberlin, in the original references cited; T. E. Savage: Proceedings of the Iowa Academy of Sciences, vol. xi, 1904, pp. 103-109; S. Calvin: Proceedings of the Davenport Academy of Sciences, vol. x, 1905, p. 19.

[10] H. F. Bain: Proceedings of the Iowa Academy of Sciences, vol. v, 1898, pp. 98-99.

[11] J. W. Holzinger and G. N. Best: Bryologist, November number, 1903; T. E. Savage: Proceedings of the Iowa Academy of Sciences, vol. xi, 1904, pp. 105 and 108.

[12] T. H. Macbride: Proc. of the Iowa Academy of Sciences, vol. iv, 1897, pp. 63-66.

[13] S. W. Beyer: Vol. vii, 1897, pp. 231-232.

[14] J. A. Udden: Vol. ix, 1899, pp. 338-339.

[15] J. A. Udden: Vol. xi, 1901, p. 1~~5~~4. 6 /

[16] F. A. Wilder: Vol. xii, 1902, pp. 130-131.

[17] T. E. Savage: Vol. xv, 1905, p. 202.

[18] T. H. Macbride: Vol. xvi, 1906, p. 532.

[19] H. F. Bain: Proceedings of the Iowa Academy of Sciences, vol. v, 1898, pp. 86-101; S. Calvin: Proceedings of the Davenport Academy of Sciences, vol. x, 1905, pp. 18-30.

[20] The writer published a note concerning them in Science, Dec. 25, 1908, p. 923.

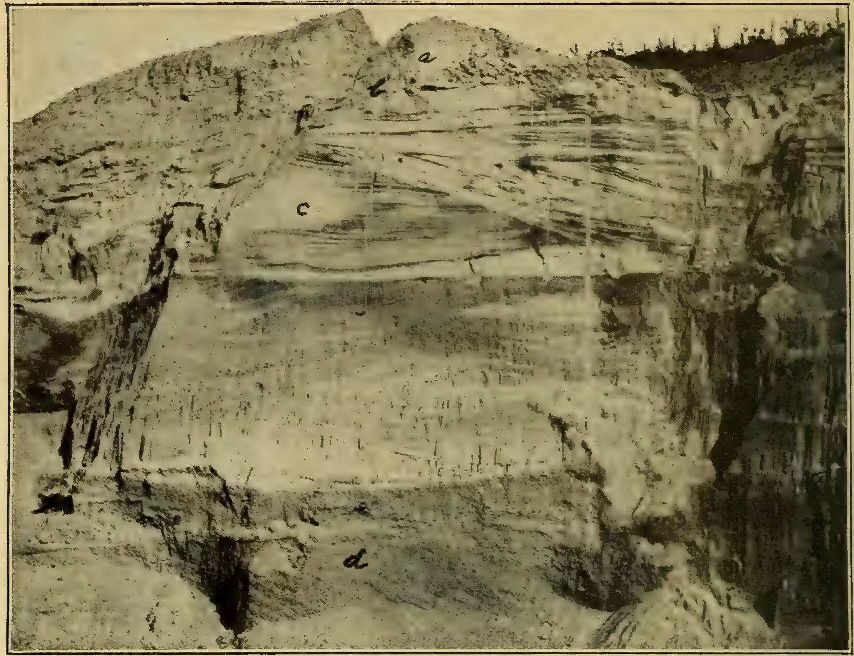

FIGURE 1.—LOOKING ALMOST DUE EAST

(*a*) Kansan; (*b*) contact line, weathered and with calcareous plates; (*c*) Aftonian sand, 21 feet; (*d*) fossiliferous Aftonian gravel, 10 feet exposed

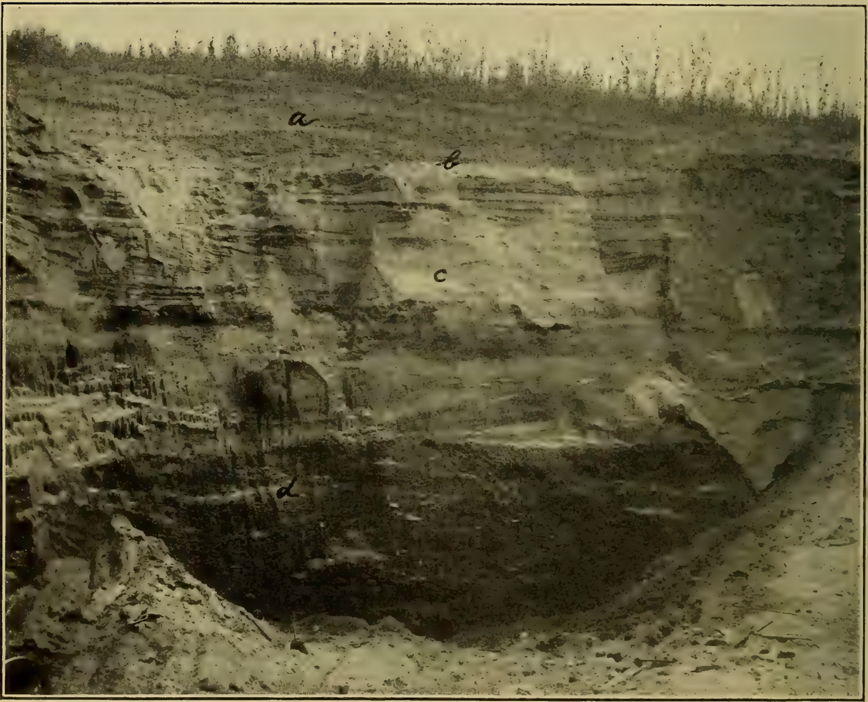

FIGURE 2.—LOOKING SOUTHEAST

(*a*) Kansan, 13 feet; (*b*) contact line; (*c*) sand, 21 feet; (*d*) gravel, 14 feet exposed

COX PIT, EAST OF MISSOURI VALLEY, IOWA

trine[21] or fluviatile,[22] and as modified drift, referring to them as "stratified drift,"[23] "gravelly drift,"[24] etcetera, but no effort was made to fix their stratigraphic relations.[25] Udden[26] evidently included them in the till, or at least considered them of glacial origin.[27]

The gravel beds of Harrison and Monona counties have heretofore received but little attention from geologists. Saint John considered them "modified drift,"[28] and Bain found "gravelly drift" in the northern part of Monona county;[29] but here also no attempt was made to definitely determine either their geologic horizon or their extent, for Saint John's observations were made in connection with a preliminary survey of that part of the state long before the modern differentiation of glacial and interglacial deposits was recognized, and Bain's studies in these counties were made incidentally, in connection with the survey of an adjoining county, and were restricted to one locality. The recent investigations, however, show not only that these sands and gravels occur in widespread beds, but that they are unquestionably Aftonian.

Description of the Beds

GRAVELS CONTAINING MAMMALIAN FOSSILS

The beds consist of interbedded and cross-bedded gravels and sands, as illustrated in plate 33, figures 1 and 2.

The gravel is water-worn and variable in coarseness, sometimes containing small boulders up to 4 inches in diameter, and consists largely of foreign materials such as might be from the drift, and with occasional fragments of fossiliferous limestones, evidently of far northwestern origin. Occasionally large boulders, chiefly of Sioux quartzite, are also found.

The beds are often strongly iron-stained, as in the exposure shown in plate 34, figure 2, the iron sometimes cementing the gravel into plates and masses of conglomerate, and occasional bands and wedges are almost black with MnO_2.

They also contain small "boulders" of light bluish gray silt or dark blue black sub-Aftonian till, densely covered with sand and fusiform or spherical in form, as if shaped by rolling on the bottom of a stream.

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[21] H. F. Bain: Reports of the Iowa Geological Survey, vol. v, 1896, p. 277; J. A. Udden: Ibid., vol. xi, 1901.

[22] J. A. Udden: Ibid., vol. xi, 1901, p. 255, and vol. xiii, 1903, p. 166.

[23] H. F. Bain: Ibid., vol. viii, 1898, p. 338.

[24] H. F. Bain: Ibid., vol. v, 1896, p. 281.

[25] Except that Macbride referred the gravel beds of Ida and Sac counties, in the same section of the state, to the Aftonian in general terms. Ibid., vol. xvi, 1906, p. 532, etc.

[26] Iowa Geological Survey, vol. xi, 1901, p. 251, etc.

[27] Ibid., p. 254.

[28] White's Report of the Iowa Geological Survey, vol. ii, 1870, pp. 177-184.

[29] Reports of the Iowa Geological Survey, vol. v, 1896, p. 281.

In these gravels were found numerous remains of extinct mammals belonging to the genera *Elephas, Mamut, Equus,* etcetera, which are discussed more fully in Professor Calvin's paper. They were especially abundant in the typical exposure shown in plate 33, and in the Peyton pit at Pisgah. These remains consist of bones, teeth, and tusks, and are more or less fragmentary and promiscuously distributed through the coarser parts of the beds, having evidently been transported and scattered by the same strong currents which moved the gravels.

A vertebra of a small fish was also collected from finer gravel. A few heavy-shelled Unios were found, but they are more or less fragmentary, the shells being chalky and very fragile. Only one species, *Quadrula metanevra* Raf., could be positively identified. The species is now common in the rivers tributary to the Missouri. Unidentifiable fragments of at least two other species are in the collection.

The abundance and wide distribution of the bones and teeth in these gravels and their comparatively good state of preservation suggest that they were not derived from older formations or carried long distances, but that the animals lived and died in comparatively close proximity to the present burial ground of their remains.

SANDS BEARING MOLLUSCAN FOSSILS

The sand beds are stratified, and sometimes interbedded and cross-bedded with finer gravel, and quite variable in fineness. They also vary in color, some being rusty red with iron, others almost black with MnO_2, and in the lower part of the deposit, beds of almost pure white sand often occur. They usually contain small, very soft white calcareous nodules.

The finer sand is sometimes cemented into plates and blocks which usually grade into loose sand below. These blocks are sometimes so massive that they have the appearance of bedded rock, as in the exposure on the east side of the Little Sioux river, near the north line of Harrison county, and at Loveland and near Council Bluffs, in Pottawattamie county, south of the Harrison county line. A little of this is shown near the middle of the lower part of plate 37, figure 2.

These finer sands contain numerous shells of fresh water and land mollusks, all belonging to modern species, which are scattered through the sand in much the same manner in which more recent shells are scattered through the sand of modern river-bars. The shells are exceedingly fragile and are difficult to handle, but a sufficiently perfect series was collected to determine the identity of the forms with species now living in the same region. The following species have been thus far identified:

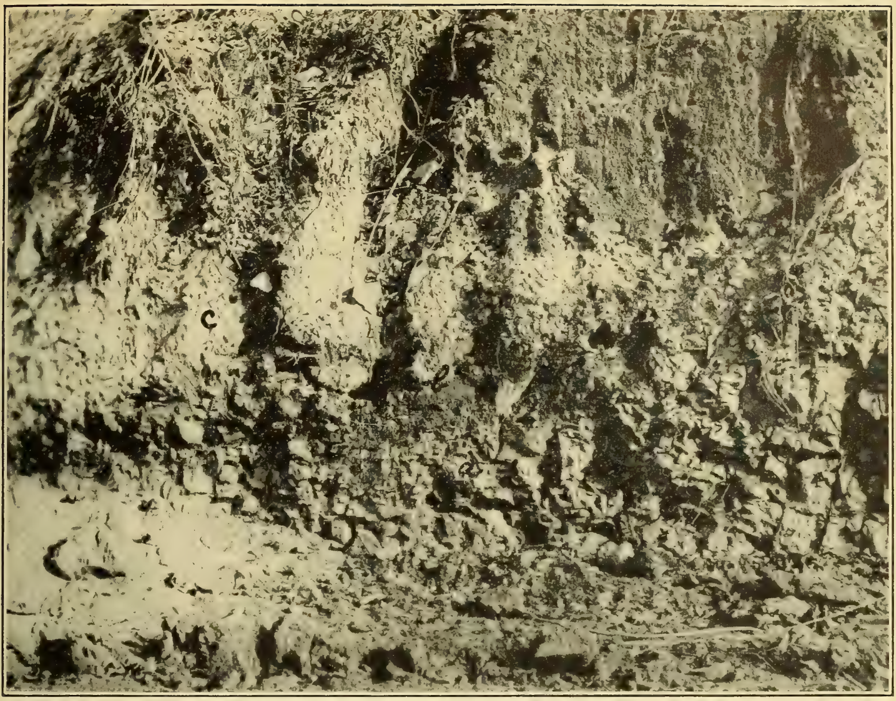

FIGURE 1.—LOWER PART NEAR SOUTH END
(*a*) Sub-Aftonian; (*b*) weathered band of (*a*); (*c*) Aftonian

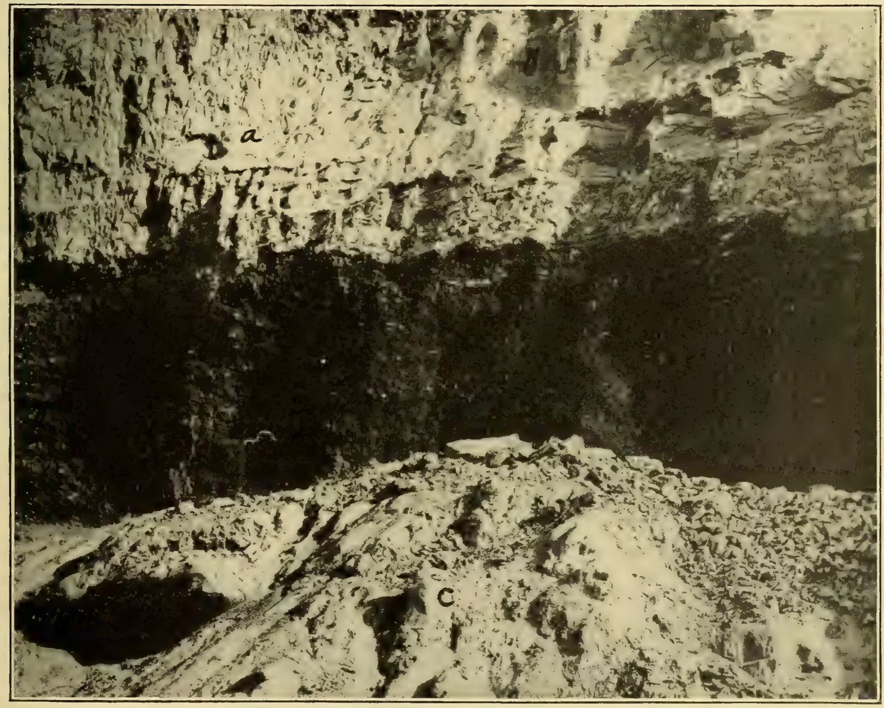

FIGURE 2.—UPPER PART NEAR NORTH END
(*a*) Kansan; (*b*) Aftonian; (*c*) talus.

COUNTY-LINE EXPOSURES OF AFTONIAN, SECTION 5, TOWNSHIP 81 NORTH, RANGE 44 WEST

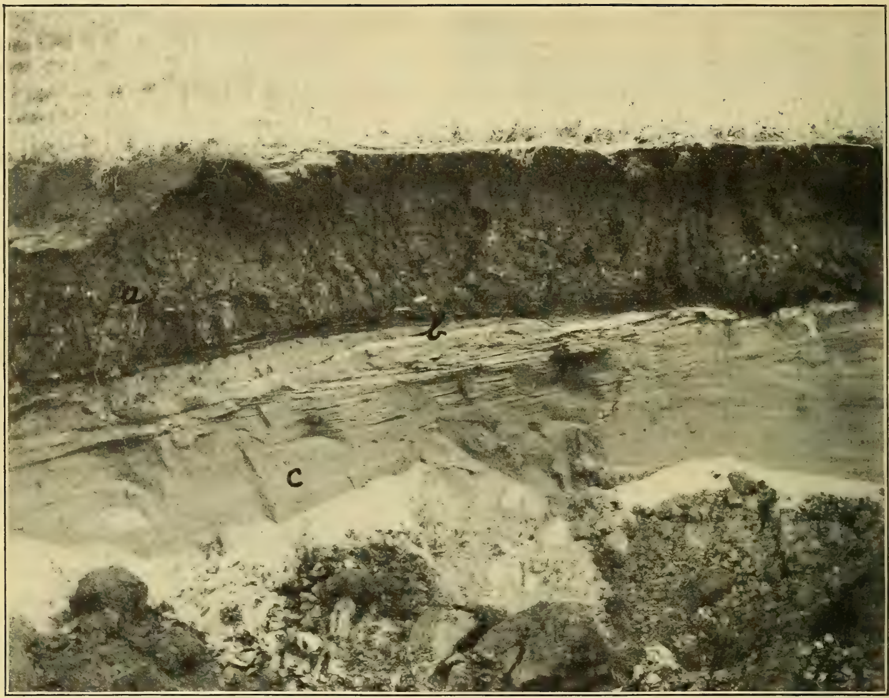

FIGURE 1.—EXPOSURE IN SERTION 7, TOWNSHIP 85 NORTH, RANGE 44 WEST

(*a*) Kansan; (*b*) contact line, weathered and with calcareous plates; (*c*) Aftonian sand

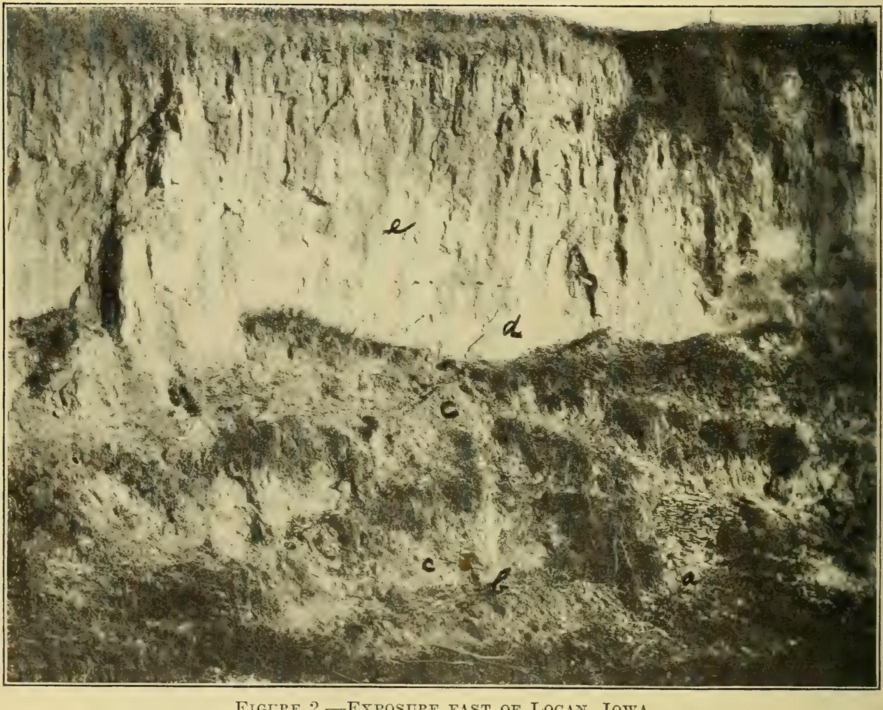

FIGURE 2.—EXPOSURE EAST OF LOGAN, IOWA

(*a*) Missourian limestone, 4 feet; (*b*) Aftonian gravel, 2 feet; (*c*) Aftonian sand, 10 feet; (*d*) Kansan joint clay (Loveland), 7 feet; (*e*) loess, 15 feet

SECTIONS SHOWING POSITION OF AFTONIAN

Aquatic Species

Sphærium sulcatum (Lam.) Prime
Pisidium —— sp.?
Valvata tricarinata Say
Valvata bicarinata Lea
Ancylus rivularis Say
Segmentina armigera (Say) H. & A. Adams
Planorbis bicarinatus Say
Planorbis parvus Say
Lymnæa caperata Say (?) Fragments
Physa —— sp. ? Fragment

Terrestrial Species

Vitrea hammonis (Strom.) Pils.
Zonitoides arboreus (Say) Pils.
Vallonia gracilicosta Reinh.
Bifidaria armifera (Say) Sterki
Pyramidula striatella (Anth.) Pils.
Pyramidula alternata (Say) Pils.
Succinea obliqua Say
Succinea avara Say

The aquatic species belonging to the genera *Sphærium, Pisidium,* and *Ancylus* are most common and most widely distributed in the beds of finer sand. All the aquatic species in the list are now found living in the same region in the streams tributary to the Missouri, and in adjoining ponds.

The fossil land shells are more local in distribution and fewer in number, only scattered individuals being found. The species are all represented in the modern fauna of the same region.

It may be worthy of note that while all the species of land shells here listed are also found in the loess, they are there never mingled with freshwater shells in the same manner.[30] On the other hand, such mingling of fresh water and land shells as is here recorded is common in all the modern alluvial deposits of the same region. The presence of these shells, then, shows that fluviatile conditions prevailed in the immediate area concerned, but that land surfaces on which the terrestrial mollusks flourished, and from which they were washed by floods, were near by.

No uniformity marks the relative arrangement of the sands and gravels. Sometimes the finer sands form the uppermost member of the series, as shown in plate 33, figures 1 and 2, and plate 35, figure 1; again, the heavy gravels occupy this position, as in the county line exposure shown in plate 34, figure 2, or the sands and gravels are indiscriminately interbedded. These differences simply indicate variations in the force of the ancient currents.

THICKNESS AND ALTITUDE OF BEDS

Where undisturbed, the sands and gravels are usually very clean, especially along the tributary valleys, but in the main bluffs of the Missouri valley they are not infrequently mingled and interbedded with silt.

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[30] Freshwater shells are exceedingly rare in the loess, and are almost exclusively Pulmonates, and such genera as *Sphærium, Ancylus,* etcetera, are unknown.

They vary in total thickness up to 40 feet, and rise to a height of 10 to 40 feet above the latest alluvial plain. But where they have been plowed and crowded by the overlying Kansan they are frequently mingled with joint clay, till, etcetera, and are often piled up to a greater height, as in Murray hill, northeast of Little Sioux, where they rise irregularly to a height of more than 100 feet above the general level of the valley.

DISTRIBUTION IN HARRISON AND MONONA COUNTIES

In the two counties under consideration the Aftonian beds are distributed along the bluffs bordering the Missouri valley,[31] and along all the principal tributaries—the Boyer, Soldier, Maple, and Little Sioux rivers. Sometimes they are present on one side of the valley, and again on the other. Thus along the Boyer, below Woodbine, they appear on the west side of the river, while in the lower course of the same valley they are on the east side. More rarely they appear on both sides, as along the Maple river, near Mapleton. This is consistent with the distribution of sand and gravel bars along modern streams.

Evidence that the Beds are Aftonian

STRATIGRAPHIC POSITION

That these sand and gravel beds are Aftonian is clearly shown by their stratigraphic position between the Kansan and sub-Aftonian drifts. This is well illustrated in the county line exposure near Little Sioux, the first exposure in which the writer definitely determined the stratigraphic position of these deposits, where a great bed of sands and gravels, not less than 15 feet in thickness, lies between the sub-Aftonian till exposed at the base of the bluff and the typical Kansan till above, both of which it meets unconformably.[32]

Both sub-Aftonian and Kansan, with the intervening Aftonian, are exposed at a number of points in this region. Such exposures were found in Monona county, in Woodward's glen, in section 17, township 84 north, range 44 west, and in a well near Castana, in section 13, township 84 north, range 44 west; in Harrison county, in section 5, township 81 north, range 44 west (the county line exposure already noted), and on Murray hill near the corner of sections 7, 8, 17, and 18, in the same township, and in the bluff above Loveland, in Pottawattamie county.*

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[31] Sand and gravel beds at several points on the west side of the river, in Nebraska, are also Aftonian.

[32] For the contact line in this exposure with the sub-Aftonian, see plate 34, figure 1; with the Kansan, plate 33, figure 2.

* More recently the writer discovered several additional similar exposures on both the Iowa and Nebraska sides of the Missouri.

In many other cases the sub-Aftonian is not in sight, but the overlying Kansan is clearly shown. This is well illustrated in the Cox pit, near Missouri Valley,[33] and in a pit near Grant Center, in section 7, township 85 north, range 44 west,[34] but the same relation is shown clearly in nearly all the exposures studied in Harrison and Monona counties.

Even in the few cases in which the Aftonian is not in contact with the sub-Aftonian or the Kansan, the position of the beds is stratigraphically consistent. Thus at Logan the bed of gravel 2 feet in thickness, with overlying sands 10 feet in thickness, lies directly on the Missourian limestone, no sub-Aftonian being present.[35] Resting on the sand is a bed of reddish joint clay,[36] and above this is fossiliferous loess. While there is no Kansan till in this section, the presence of the Loveland makes the position of the Aftonian beds consistent.

At Denison, in Crawford county, a bed of cross-bedded sand and gravel 35 feet in thickness lies immediately below a bed of fossiliferous loess, evidently post-Kansan, on which rests a layer of dune sand, possibly derived from the Iowan, and over this appears another deposit of later loess. While neither Kansan nor sub-Aftonian appear in this section, the position of the bed below the older loess, the similarity of its cross-bedding, etcetera, to that of undoubted Aftonian, and the presence of Aftonian fossils, such as fragments of *Sphœrium,* and bones of large mammals, such as *Elephas* and *Cervalces,* all indicate that the beds are Aftonian.

That the beds herein discussed are not merely a comparatively recent outwash covered by a slumping of the Kansan along the bluffs of modern valleys is demonstrated by the fact that well-sections show that they run well back into the bluffs.

Thus about 15 rods back from the Cox pit a well excavation revealed Aftonian beds 40 feet below the surface, which is here about 60 feet above the top of the Aftonian in the pit.

At Logan, a well dug about 5 rods from the face of the bluff showed Aftonian sand at a depth of about 28 feet. The exposure shown in plate 35, figure 2, is only a short distance above (north) of this well, and also furnishes evidence of the same kind, for the excavation here extends at least 3 or 4 rods into the bluff, yet the Aftonian is well developed.

A well east of the Wallace pit, near Little Sioux, Iowa, penetrated into a bed of gravel at a depth of about 90 feet. The well is on a high bench several rods back from the bluff in which the pit is located. The gravel in the well is probably Aftonian.

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[33] See plate 33, figure 2.

[34] See plate 35, figure 1.

[35] See plate 35, figure 2.

[36] This has been referred to as "gumbo" in the type locality at Loveland by Udden and the writer (see Bulletins from the Laboratories of Natural History of the State University of Iowa, vol. 5, 1904, p. 348). It evidently bears the same relation to the Kansan as the Buchanan gravels, and the name *Loveland* is here proposed for it.

Other well-borings, though less definite, also indicate that the Aftonian gravels extend well into the bluffs.

THE AFTONIAN INTERGLACIAL WITH MILD CLIMATE

That these sands and gravels belong with neither the sub-Aftonian nor Kansan drifts is shown by the following evidence:

1. They are not sub-Aftonian, because in every case examined they lie unconformably on the older drift, the old oxidized and weathered surface of which sharply marks the line of division between the two deposits.[37]

2. They are not Kansan, for in nearly all the exposures Kansan is shown clearly resting unconformably on them, with calcareous plates (nodular), cemented sands and gravels, and strongly oxidized materials sharply defining the line of division.[38]

Moreover, evidence is furnished by several exposures that the Kansan passed over the Aftonian beds while the latter were frozen, and plowed and tilted them in mass or disturbed and folded them in intricate fashion.

Thus in the McGavern pit, south of Missouri Valley, the Kansan presents a sharp but very irregular line of contact with the Aftonian, and cross-bedded and stratified masses of the latter are twisted and folded until in some places they are nearly vertical. This is shown especially well in plate 36, figure 2, which represents the south end of the section shown in plate 36, figure 1. Here the line between the Kansan and Aftonian is very sharp, and the former is shown projecting into and against the latter, which has had its strata pushed into an almost vertical position.

The Murray Hill exposures[39] show that both the Aftonian and sub-Aftonian were crowded and folded by the Kansan. The Aftonian gravels have been here pushed up to an unusual height—as noted, more than 100 feet above the valley. In these exposures sub-Aftonian and Aftonian masses ("boulders") are common in the lower part of the Kansan, which had evidently not only moved great masses of frozen gravels (for the latter, even when most folded and tilted, show the original stratification and cross-bedding), but also plowed into the underlying sub-Aftonian, which is sometimes folded, and shows cleavage, concentric with its face or front, evidently due to the great pressure of the advancing Kansan.

A pit below Woodbine also shows a tilted layer of Aftonian, with a mass of mingled and folded sub-Aftonian, Aftonian, and Kansan in front of it, as though the whole tilted Aftonian mass had been moved forward.

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[37] See plate 34, figure 1.

[38] See plate 33, figures 1 and 2; plate 34, figure 2, and plate 35, figure 1.

[39] See plate 37, figure 1.

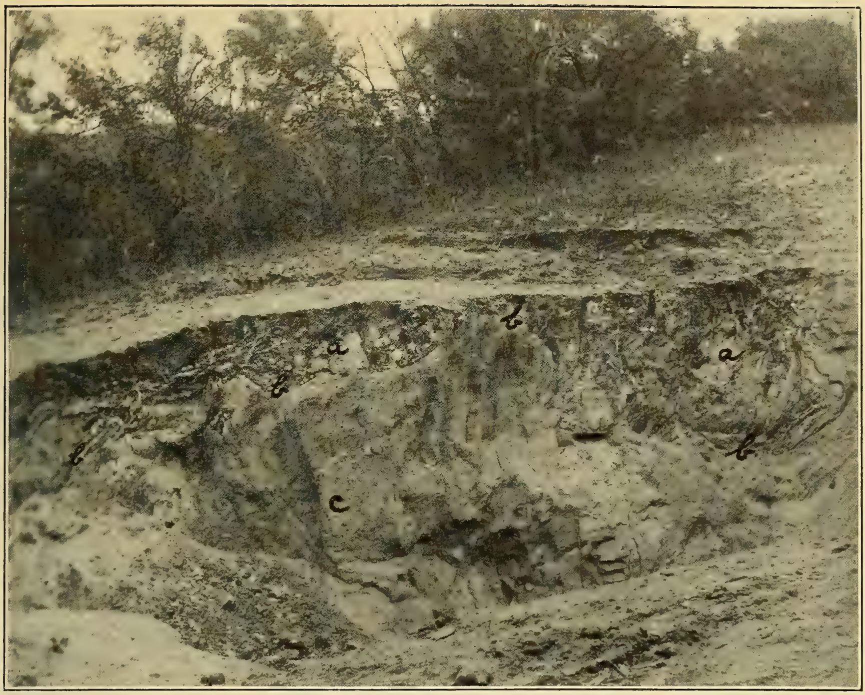

FIGURE 1.—LOOKING ALMOST EAST

(*a*) Kansan; (*b*) irregular line of contact, showing folding; (*c*) Aftonian, more or less disturbed

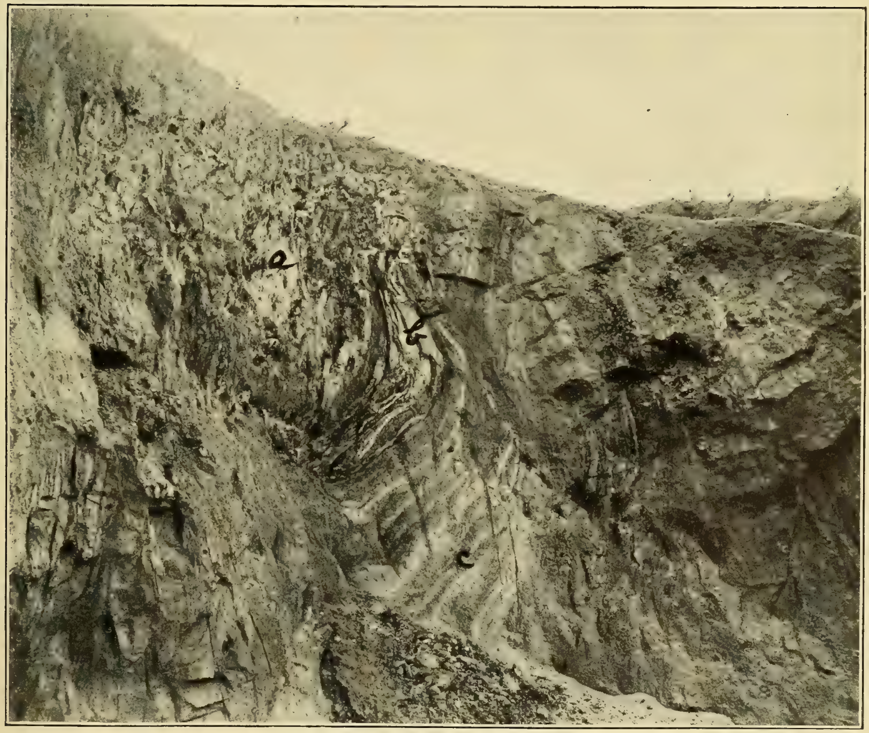

FIGURE 2.—LOOKING EAST OF SOUTH

(*a*) Kansan; (*b*) contact line; (*c*) tilted Aftonian gravel, evidently pushed into an almost vertical position by (*a*)

McGAVERN PIT, SOUTH OF MISSOURI VALLEY, IOWA

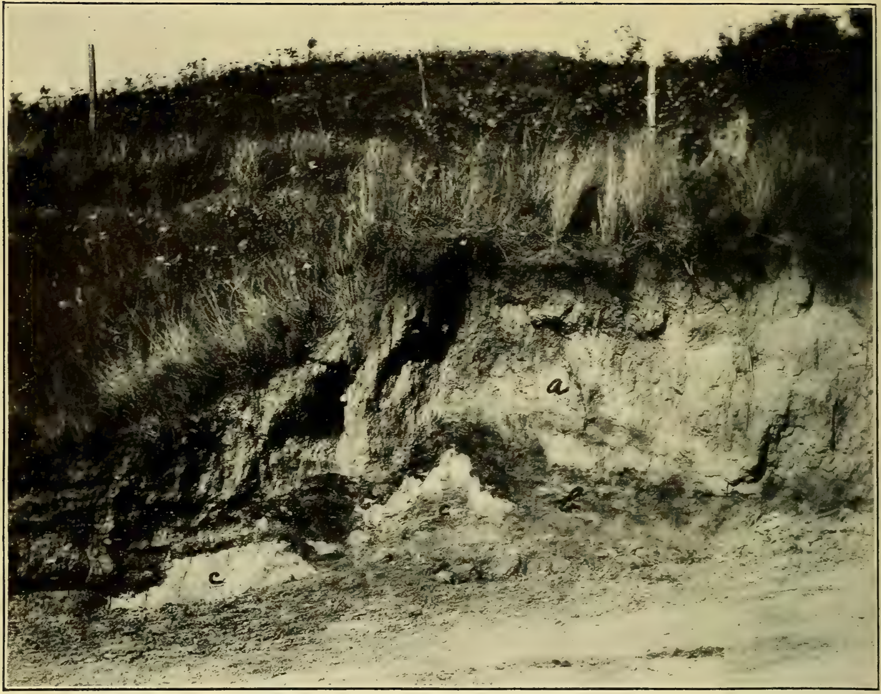

FIGURE 1.—A FOLDED AFTONIAN BED

(*a*) Kansan; (*b*) oxidized and folded bed of Aftonian gravel; (*c*) Aftonian white sand

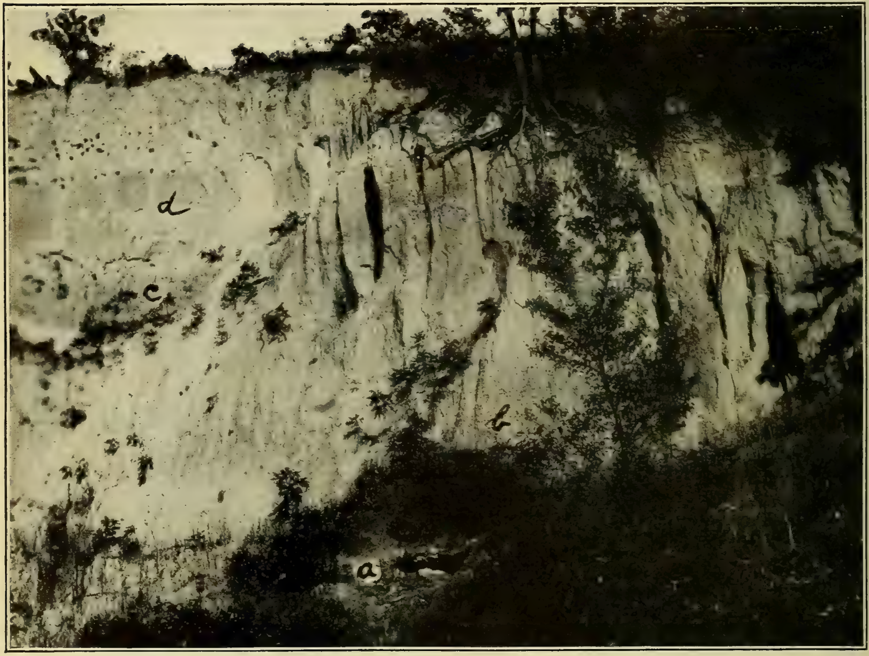

FIGURE 2.—THE LOVELAND BLUFF, POTTAWATTAMIE COUNTY

(*a*) Sub-Aftonian, more or less folded, and the upper part with sand cemented into blocks; (*b*) Kansan; (*c*) red joint clay, the Loveland; (*d*) loess

EXPOSURES SHOWING FOLDED AFTONIAN GRAVELS

Other exposures showing the folding and tilting of Aftonian gravels by the Kansan are found near Mapleton and Grant Center, in Monona county; Pisgah, in Harrison county; Smithland, in Woodbury county, and Loveland, in Pottawattamie county. All the larger pits already mentioned also show this in their uppermost portions.[40]

3. The sand and gravel beds are not glacial, but interglacial. That the materials were deposited in streams is shown by the fact that they are water-worn, cross-bedded, with frequent interbedding of sand and gravel, the latter deposited by stronger currents, and that they contain fluviatile shells, with such intermingling of land shells as is common in the same region in modern alluvial deposits.

That the climate was mild during this interglacial period is shown by the presence of the large numbers of herbivorous mammals, which required a vigorous flora for their maintenance, and of fresh-water and land mollusks, which are identical with species now living in Iowa. The aquatic shells suggest the same biotic conditions as exist in the state today, and the land shells required plant-covered land surfaces on which they could find food and shelter, and these surfaces were not radically different from those which prevail in Iowa today, if we are to judge from the identity of the land shells.

The abundance of MnO_2 in the Aftonian beds also suggests the presence of a large amount of organic matter.

THE AFTONIAN IN OTHER COUNTIES

The Aftonian beds extend also into counties other than Harrison and Monona, in the western part of the state. Thus the gravels at Sioux City,[41] in Woodbury county, between Loveland and Council Bluffs, in Pottawattamie county, at Denison, in Crawford county, and between Glenwood, in Mills county, and the northern part of Fremont county, are certainly Aftonian, as the writer has ascertained by personal examination, and those described by Bain from Plymouth county[42] and by Udden from Mills county[43] are evidently the same. Thus it will be seen that the Aftonian is well represented in the western part of Iowa.

CONCLUSIONS

The conclusions may be briefly stated as follows:

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[40] A fine illustration of the same kind is also found in the eastern part of the state, in Muscatine, near Hershey avenue, where the Aftonian and sub-Aftonian have been plowed and folded by the Kansan in a most complicated manner.

[41] See H. F. Bain's account in the Report of the Iowa Geological Survey, vol. v, 1896, p. 277.

[42] Reports of the Iowa Geological Survey, vol. viii, 1898, p. 338.

[43] Ibid., vol. xiii, 1903, p. 165.

1. Extensive deposits of sands and gravels in the western part of Iowa are definitely referred to the Aftonian stage.
2. A distinct and quite extensive molluscan and mammalian fauna is revealed in these Aftonian beds for the first time.
3. The climate of the interglacial Aftonian stage was mild.
4. The Aftonian beds are widely distributed along ancient and modern river courses in Iowa.

Aftonian and Nebraskan—an Addendum

Since this paper was written the writer has made additional observations on the Aftonian and sub-Aftonian deposits, especially along the Missouri river in Iowa and Nebraska, and along the Big Sioux river, and in various other localities in Iowa. These observations demonstrate that both deposits are of very wide extent.

Additional fossiliferous Aftonian beds were found near Omaha, Nebraska, and in Plymouth and Woodbury counties in Iowa, and much additional material was obtained from the exposures previously studied, especially those at Missouri valley and Turin, Iowa.

Quite recently the writer discovered extensive beds of Aftonian sands and gravels, the latter frequently massed into ledges of conglomerates, resting on well developed strata of pre-Kansan, or sub-Aftonian drift, in South Omaha and near Florence, Nebraska, and between Council Bluffs and Crescent, Iowa. The tough, impervious, bluish-black till which has been known as the sub-Aftonian or pre-Kansan drift in Iowa, is here so well developed, reaching an exposed thickness of more than 15 feet and extending for several miles along the base of the bluffs on both the Nebraska and Iowa sides of the Missouri river, and moreover occurs at so many other localities in Iowa, Missouri, and Nebraska, that it can no longer be regarded as merely a remnant, but should rank with other well developed drift sheets.

The terms pre-Kansan and sub-Aftonian have been used merely to designate the position of this drift sheet; the name Albertan was originally applied to a deposit which can not be correlated with this drift, and which is not now regarded as glacial; and the doubtful Jerseyan can not be connected with the sheet here discussed. This leaves it without a name, and in view of this fact, and of the wide distribution of this formation, the name *Nebraskan* is proposed for it. The type exposures are located in the Missouri bluffs in South Omaha and above Florence, Nebraska, and 4 miles north of Council Bluffs, Iowa. The name Nebraskan was suggested to the writer by Professor Calvin.

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STRIATIONS AND U-SHAPED VALLEYS PRODUCED BY OTHER THAN GLACIAL ACTION[1]

BY EDMUND OTIS HOVEY

(Presented orally before the Society December 29, 1908)

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INTRODUCTION

Geologists and others are so much in the habit of considering striations and grooves in rock surfaces, U-shaped valleys, and hanging valleys to be conclusive proofs of glaciation that it will be of interest to cite some particularly striking instances of such features that have been in no way connected with ice action. The illustrations accompanying this note tell the whole story. They have been selected from the photographs taken by me upon three expeditions to the Lesser Antilles undertaken for the American Museum of Natural History in 1902, 1903, and 1908. The conditions were either consequent upon or revealed by the 1902-1903 eruptions of Mount Pelé of Martinique and the Soufrière of Saint Vincent. Perhaps similar features may be known elsewhere, without an explanation having been apparent.

The eruptions of Mount Pelé in 1902 and 1903 were characterized by the emission of unnumbered, probably hundreds, of exploding steam-clouds which were saturated with dust formed of comminuted lava (augite-andesite). It is evident that an enormous excess of water vapor was contained in the lava and that the vapor was under great pressure in the liquid rock. As the lava reached the orifice of the conduit, pressure was relieved suddenly, and the steam expanded and continued to expand with explosive violence, breaking up the lava to all degrees of grain, from great blocks 10 meters or more across down to impalpable dust. The fragments when formed were angular, but attrition in the eruption cloud and against the surface of the ground rounded the contours of the grains, particularly the larger ones and the great masses. Under the microscope the fine dust is seen to be highly and sharply angular. In the field the ejected blocks usually show bruised and rounded angles and corners. The first eruption clouds, furthermore, reached the surface in the bottom of a vast pit-like crater about 1 kilometer across. Their force of explosive expansion was confined on three sides by practically vertical walls from 300 to 650 meters high, but the southwest side of the rim was breached to the bottom of the crater by a great V-shaped cleft. These two factors[2] prevented the free expansion of the exploding cloud and gave direction to it, confining it to a narrow sector of a circle, bounded on the northwest by the high bluffs along the right bank of the Rivière Claire, but without any sharp surface delimitation on the other side. This was the "zone of annihilation" often referred to in my own and other early reports upon the eruptions. The content of dust in the cloud was such as to make part of it heavier than the atmosphere, so that it clung to the ground, rolling and sliding over its surface.

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[1] Published by permission of the American Museum of Natural History.
Manuscript received by the Secretary of the Society August 30, 1909.

STRIATIONS

SAND-BLAST ACTION ON MOUNT PELÉ

Within the sector thus described all the bluffs facing the crater were smoothed, scored, and grooved as if by the action of a stupendous sand-blast or the passage of a well sanded glacier. This sand-blast action at Pelé has been noted by Professor Lacroix,[3] me,[4] and Doctor Anderson,[5] but only in a preliminary or very cursory manner, whereas the occurrence is worthy of more extended notice.

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[2] Some authors have argued for the existence of an inclined opening to the volcano's conduit to explain the marked orientation of the eruption cloud. The assumption of such specific inclination of the vent seems unnecessary, since the two factors mentioned would be sufficient to produce the effect, but a discussion of the cause of the confinement of the destructive blast to a narrow zone is beside the purpose of the present article.

[3] A. Lacroix: Rollet de l'Isle and Giraud. Comptes Rendus de l'Acad., cxxxv, p. 387. Meeting of September 1, 1902.

A. Lacroix: La Montagne Pelée et ses Eruptions, 1904, p. 217.

[4] Bull. American Museum of Natural History, vol. xvi, October, 1902, p. 363, pl. xlix, fig. 2. American Journal of Science, IV, vol. xiv, November, 1902, p. 345, fig. 15. Comptes Rendus, ix, Congr. Géol. Internat., 1904, p. 716.

[5] Philosophical Transactions of the Royal Society of London, series A, vol. 208, 1908, p. 300, pl. 25, figs. 1, 2.

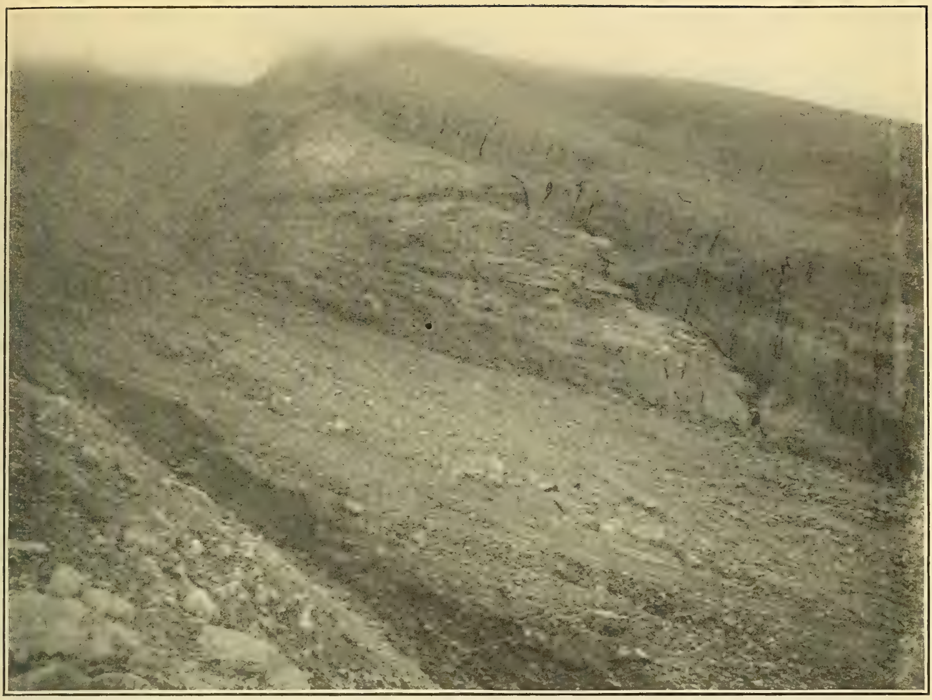

FIGURE 1.—MOUNT PELÉ: ROCK MASS AND TUFF AGGLOMERATE OF CRATER RIM

Showing grooving due to sand-blast action of eruption clouds

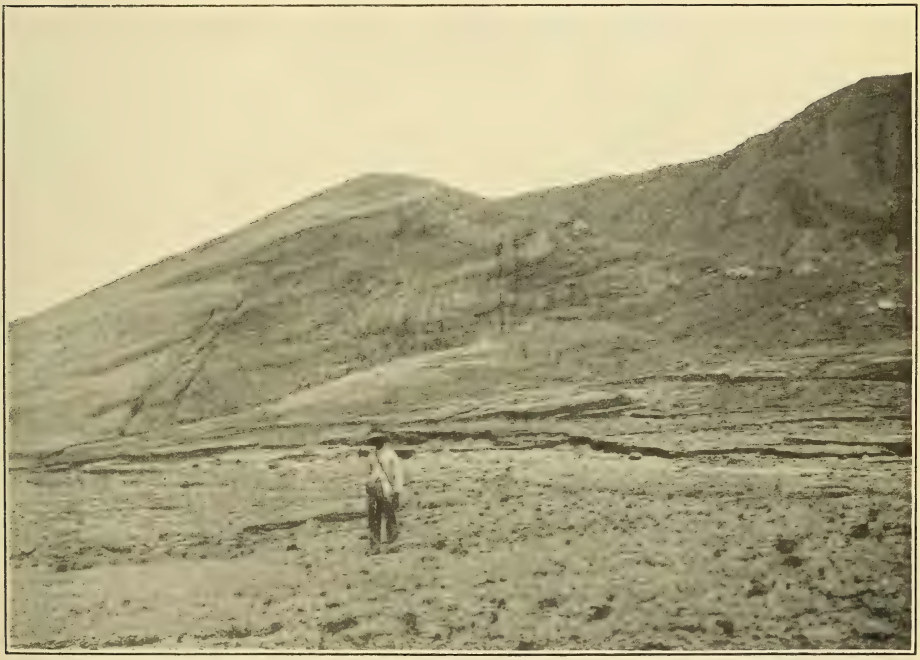

FIGURE 2.—MORNE LÉNARD, MOUNT PELÉ

The nearly horizontal grooving was caused by sand-blast action of eruption clouds

VOLCANIC SAND-BLAST ACTION ON MOUNT PELÉ

Standing like a sentinel upon the west rim of the crater, and forming the northern point of the V-shaped cleft often referred to, was the mass of old lava known as Petit Bonhomme. This rock-mass was directly in the path of all the heavy eruption clouds. It is scored with horizontal and inclined grooves on the vertical north, east, and south faces. Another rock-mass even more beautifully striated is one in the south side of the V-shaped cleft and about midway of the original vertical height of the wall (see figure 1, plate 38). These two examples are nearest to the center of activity and are particularly instructive, because they show grooving and polishing of massive rock, the grooves being many meters long, but of undetermined depth.

The V-shaped cleft was at the head of the old gorge of the Rivière Blanche, and that gorge was the course of many dust-laden steam-clouds (the *nuées ardentes* of Lacroix). The origin of the first of these clouds has been explained. Directly after the first great outbreak the activity of the volcano manifested itself in building up out of "solid" lava (that is, of original material, not of débris) a cone within the old crater. The material was extremely viscous and it hardened as it rose from the conduit, a process that was favored by the expansion of the contained water vapor, which rapidly reduced the temperature of the mass below the point of solidification. An extremely steep-sided cone or dome was the result, with vertical walls and 37 degree slopes of slide rock on its southwest side above the head of the old Blanche gorge. As the cone rose, the explosions occurred most frequently and violently in the southwest section of its upper part. The dust-saturated clouds therefore rolled down the steep slope of the new cone, gaining velocity and force as they went. The velocity attained by many of the clouds in the upper part of their course (as far as Morne Lénard) was determined by angular measurements from the French observatory on Morne des Cadets, only 9 kilometers distant, to be as much as 50 meters per second. The cloud that swept over Saint Pierre on the fatal 8th of May had a velocity of not less than 130 to 150 meters per second 8 kilometers from the crater, as is shown by the moment of the force required to overturn the iron statue of Notre Dame de la Garde on the bluff of Morne d'Orange, south of the city (Lacroix).

Such dense clouds moving with such velocity were of course able to do much erosive work. Two examples of what was done on surfaces of solid andesite have been given, but illustrations of the effect produced on the old tuff-agglomerate composing the major portion of the mountain were much more numerous.

About 1.8 kilometers below the V-shaped cleft in the rim of the crater the gorge of the Rivière Blanche turns sharply westward through an angle of 90 degrees to skirt a ridge called Morne Lénard.[6] Between Morne Lénard and the main mass of the mountain there is a comparatively low col over which rushed part of each cloud that was divided into two parts on striking the narrow front presented by the morne. The surface of the ground here was completely denuded of soil and the tuff-agglomerate was scored with hundreds of parallel straight grooves many (10 to 15) meters long and several (2 to 10 or more) centimeters deep. Such grooves in the side of Morne Lénard are shown in figure 2, plate 38, made from a photograph taken in May, 1908. Figure 1, plate 39, is a near view of a part of the same surface, taken in February, 1903. The latter view shows, too, the manner in which the comparatively hard component fragments of the agglomerate were planed off without being dislodged from the softer matrix. Such fragments when removed from their present surroundings, either naturally or artificially, would make good imitation "glacial bowlders;" or the whole surface, if buried beneath an accumulation of volcanic débris, would have close resemblance in appearance to a glaciated surface under a covering of till. The photograph given in figure 2, plate 38, furthermore brings out well the rounded, glaciated appearance of the morne as viewed from the east and north, the lower part closely resembling a true glacial *roche moutonnée*.

Other bluffs showing the sand-blast action typically were observed along the right bank of the Rivière Claire, on the right bank of the Blanche opposite Morne Lénard, on both walls of the Rivière Sêche gorge (see figure 2,[7] plate 39), and elsewhere—in fact, wherever in the zone of annihilation a surface was opposed to the advance of the eruption clouds. The direction taken by the striæ depended on the position of the striated surface with relation to radii drawn with the crater as a center.

AVALANCHE ACTION ON MOUNT PELÉ

The Morne Saint Martin is a rather flat ridge sloping away from the crater and not fully exposed to the fury of the volcanic sand-blast. Here corrasion was observed, with grooves and striæ running at an angle to the radii of the zone of annihilation which were not to be accounted for by reference to the eruption clouds for their origin. This flat ridge is midway of the mountain and has a slope of 10 to 15 degrees, the slope below being from 3 to 5 degrees, and the slope of the outside of the old cone above being about 20 to 28 degrees. During intervals of mild activity

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[6] Erroneously called Morne Saint Martin in my earlier papers. The real Morne Saint Martin is a less prominent ridge south and east of Morne Lénard.

[7] This is a near view of part of the scored bluff illustrated in Bull. American Museum of Natural History, vol. xvi, pl. 49, fig. 2.

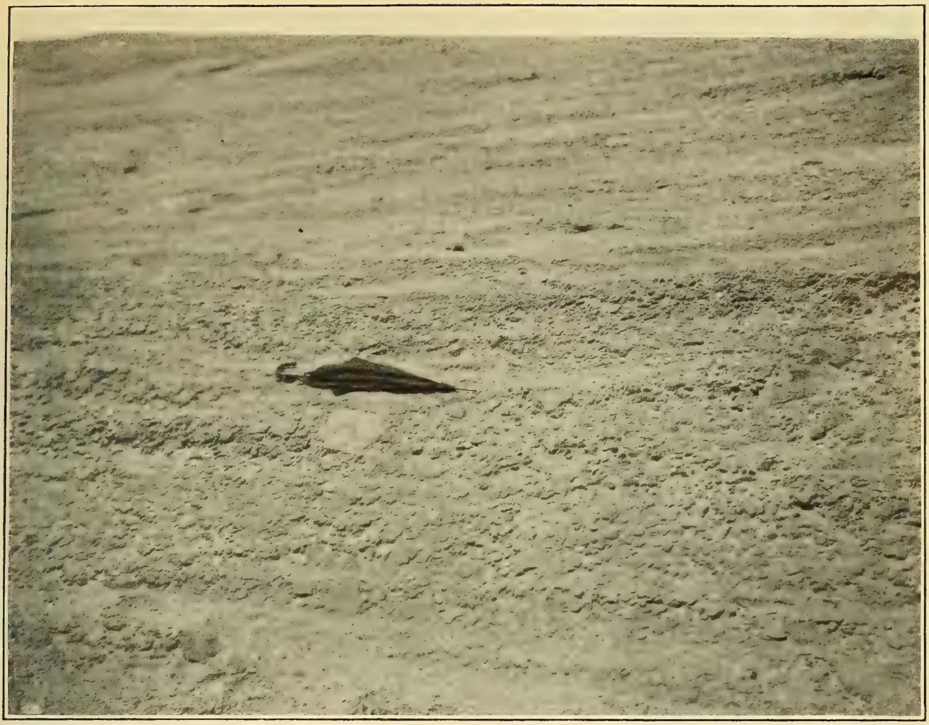

FIGURE 1.—MORNE LÉNARD, MOUNT PELÉ
Near view of volcanic sand-blast action. The rock is tuff agglomerate

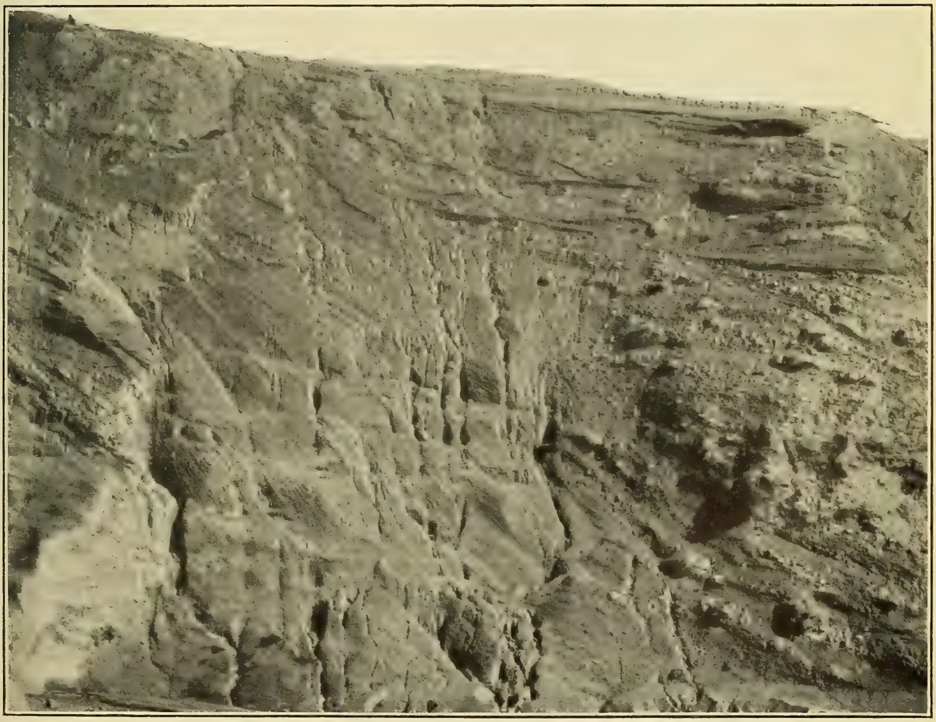

FIGURE 2.—VERTICAL CLIFF BESIDE RIVIÈRE SÈCHE, GROOVED OBLIQUELY BY VOLCANIC SAND-BLAST

VOLCANIC SAND-BLAST ACTION ON MOUNT PELÉ

ash accumulated to a thickness of 15 to 30 centimeters or more on the steep part of the old cone near the crater. From time to time the coat of new material became water-soaked from the heavy tropical rains and slid down the mountain in more or less of a sheet avalanche. On the collecting ground of the steep upper cone planation and grooving were not prominent, but on the middle ground of the Morne Saint Martin, where the force of the avalanches spent itself, planation and grooving were pronounced. In June, 1902, the striated surface of the old agglomerate, with here and there a heap of unassorted ash upon it, suggested closely the appearance of a regularly glaciated surface with its overburden of till. At the lower end of the slope of the morne there is a flat transverse valley, with a short, abrupt rise below it, before the lower slope of 3 to 5 degrees begins. The avalanches were checked here and diverted into the canyon of the Rivière Sêche, apparently doing no more planation of the kind described.

Rounded and subangular pebbles and bowlders were seen in abundance in the new ash, but none was noticed showing striations to indicate that it might have been an agent or one of the tools in producing the sand-blast or the avalanche abrasion, though it seems as if diligent search might have brought some to light.

SAND-BLAST ACTION ON THE SOUFRIÈRE

Such sand-blast work as that just described as occurring in many places on Mount Pelé was likewise observed on the Soufrière of Saint Vincent, but through the nature of the old agglomerate and the fact that the soil was not so extensively removed, the evidences of the abrasion seem now to have been obliterated by atmospheric erosion and the growth of vegetation. In 1902 an interesting feature of the sand-blast erosion was the sharpening and charring of the ends of tree roots and branches that pointed toward the crater. Planing due to the sliding of the new ash over the old agglomerate ridges was not noted in Saint Vincent, but the eroding power of sliding water-soaked ash and ash-saturated water was manifest in another and perhaps more interesting fashion—by the excavation of the U-shaped valleys about to be described.

U-shaped Valleys

Several of the radial valleys on the Soufrière of Saint Vincent show the U-shaped cross-section in a rock gorge that is usually thought to be confined to valleys that have been excavated by the action of glaciers. These Saint Vincent valleys, though small, are typical, the best and most accessible that I have seen being the Larikai and Roseau gorges in the western (leeward) side of the volcano. In the Larikai gorge, about 500 meters from the sea, the bottom of the canyon is crossed by a broad, heavy bed of andesitic lava. In this rock there has been carved the perfectly U-shaped channel that is shown in figures 1 and 2 of plate 40. This is 8 to 10 meters wide, 4 or 5 meters deep, and about 50 meters long.

The explanation of this form of cross-section is hinted at in figure 2, plate 41, which shows an overloaded streamlet in the Larikai gorge depositing its excessive burden of sand and gravel in a rock basin at the foot of a fall (see also figure 2, plate 42). This illustrates the tendency of moderate showers to bring down loose material from the steep slopes of the watershed and fill the hollows in the bottom of the gorge (see also figure 2, plate 40, and figure 1, plate 41) and the gorge itself. Another circumstance contributing to the filling of these gorges with loose, angular material is the constant disintegration undergone by the almost vertical bluffs of new ash surmounting the equally steep old ash. During dry weather there is a continual shower of pebbles and sand grains down the faces of the bluffs, building débris cones at their bases, as is shown in figure 1, plate 44. Going back still farther, we know that the eruptions of 1902-1903 threw enormous quantities of lava fragments of all sizes into the gorges and onto the slopes draining into them, and filled more or less completely the radial valleys of the mountain, furnishing vast store of abrasive material for eroding the gorges (figure 1, plate 42, and figure 1, plate 43).

The bottom of the old gorges being filled to a greater or less extent by one or all of these ways, torrential rains such as are frequent in the tropics, particularly in the rainy season, soak the accumulations of loose ash and gravel past the point of equilibrium and the semi-fluid mass rushes with violence down the slopes and through the gorges into the sea. Figure 2, plate 42, shows such a mud flow falling over a precipice into the sea from the valley next north of the Larikai valley, Saint Vincent. The viscosity of these mud flows and their resultant transporting power was patent to every observer of the Mount Pelé and Soufrière eruptions. On my first expedition to Martinique I crossed the gorge of the Rivière Sêche, June 24, 1902, barely in advance of a torrent of black mud 3 or 4 meters deep that bore along on its surface bowlders 1.5 meters in diameter as if they had been corks. A flood in the Rivière de Basse Pointe, June 9, 1902, brought down from the mountain a huge rounded bowlder 3 meters across, which it left perched on a pier of the railroad bridge near the Usine Gradis, 4.5 meters above the bed of the stream, after the flood had subsided. Such examples of the viscosity of the mud torrents following on

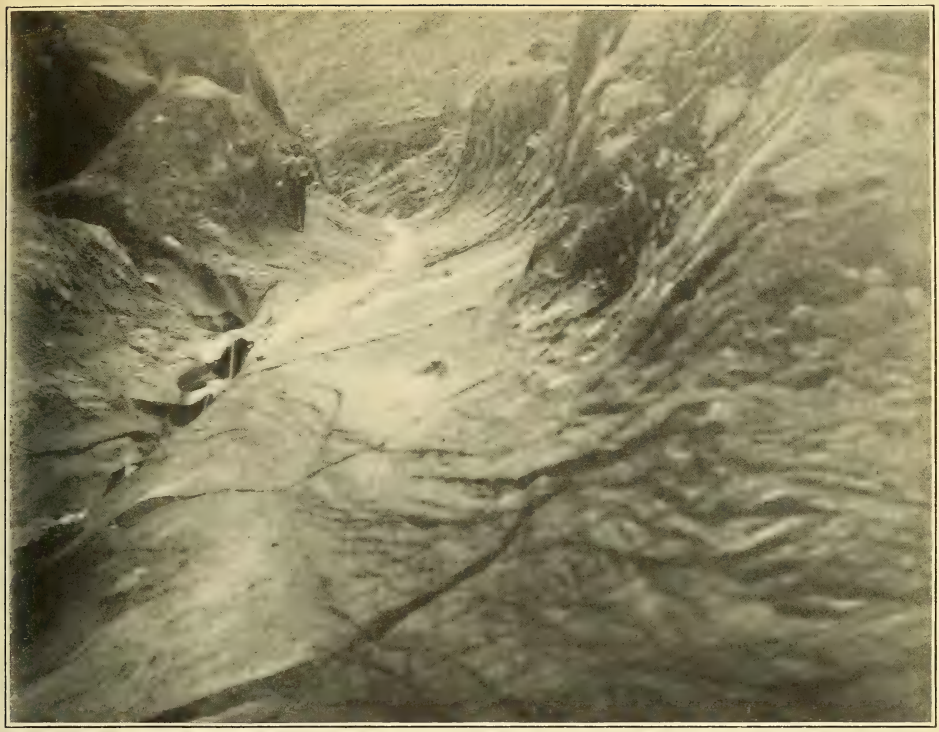

Figure 1.—Larikai Valley, the Soufrière, Saint Vincent

U-shaped rock gorge, about 500 meters from the sea, looking up stream

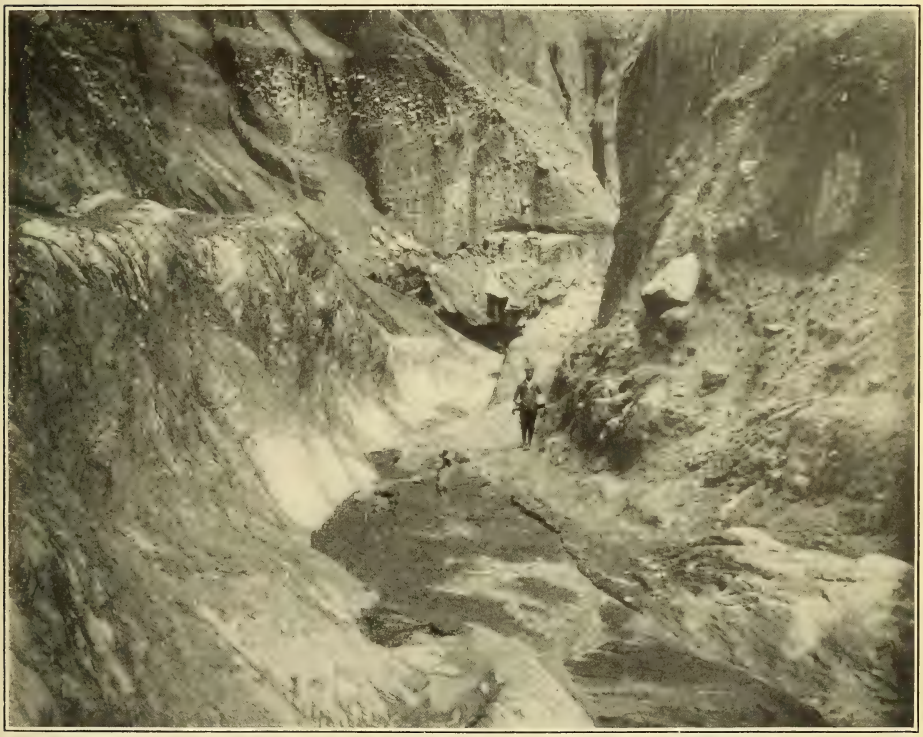

Figure 2.—Larikai Valley

Looking down stream through same gorge. Shows accumulation of sand in the hollows

U-SHAPED ROCK GORGES OF THE SOUFRIÈRE

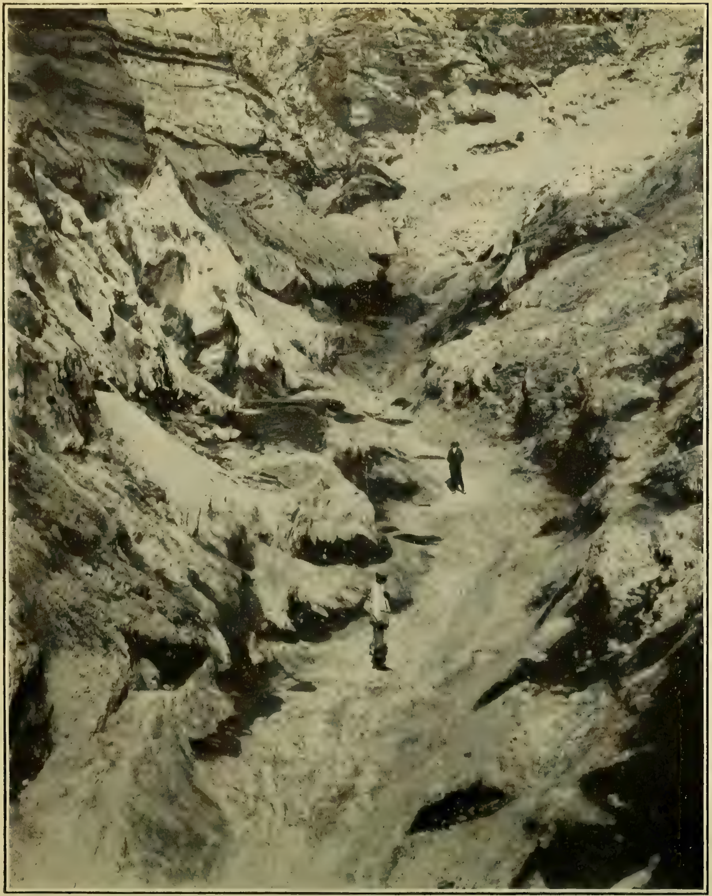

Figure 1.—Larikai Valley

The gorge shown in plate 40 as it appeared in March, 1903, with part of its ash still in place

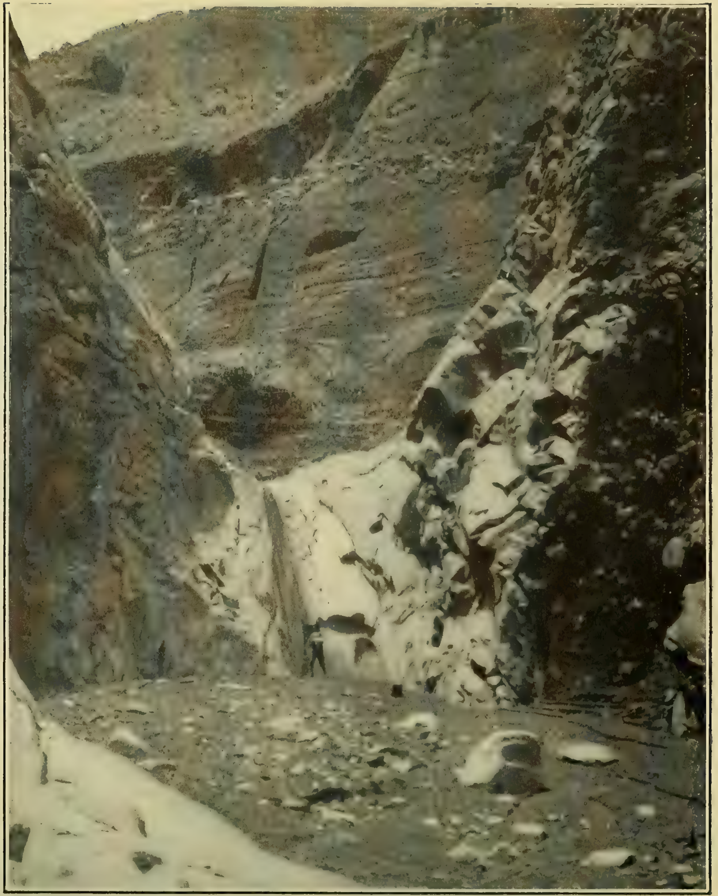

Figure 2.—Larikai Valley

Rock gorge about 1.5 kilometers from the sea. Overloaded streamlet is depositing volcanic sand in the basin

U-SHAPED GORGES OF THE SOUFRIÈRE

the deforestation of the mountains and the deposit of a mantle of loose ash on the denuded slopes might be greatly multiplied from both Martinique and Saint Vincent, but those given suffice to make clear the points that the valleys under consideration have been traversed frequently by streams of thick pasty or semi-fluid matter, and that these streams were armed with angular and subangular sand and gravel, by means of which they excavated U-shaped gorges in the beds and dikes of rock encountered in their course.

It is improbable that this corrasion of a U-shaped section should continue after the watershed becomes covered again with vegetation, because then there will be no accumulating supply of loose angular material to form mud flows and provide the floods with grinding tools. Nor is it at all likely that the phenomenon described is a new one or has been produced even in Saint Vincent by the recent eruption alone. The rock beds in which these U-shaped gorges are so beautifully developed lie in the lower reaches of the Larikai, Roseau and other valleys through which has been carried débris of the numerous eruptions of the Soufrière that have constructed the entire upper 1,000 meters of the volcano.

Where the crevicing of the rock-mass has been favorable, the impact of stones hurtling down the stream bed has broken off chips from the bed rock, producing a good imitation of the "chatter" marks made by a glacier.

The cross-section of the gorges of the headwaters of the Wallibu, the principal stream of the leeward side of the mountain, was not observed except from above, on account of the inaccessibility of the region. The lower and accessible part of the Wallibu gorge is through beds of old agglomerate, with here and there a comparatively small bed of old lava. The very bottom of the gorge is usually concealed by the fresh débris brought down since the recent eruptions, but where the sides are of the agglomerate they come abruptly and sometimes almost at right angles to the floor. The stream is aggrading this part of its bed. About 3 kilometers from the coast one encounters rock forming the bottom of one side of the gorge and suggesting a U-shaped section, except where the columnar structure of the lava beds has caused the section to be nearly or quite rectangular.

All the streams of the denuded portion of the Soufrière on its windward side are tributaries of the Rabaka river. The principal are four in number, and they have deeply incised the side of the cone, exposing to view several massive beds of lava forming the floor of the valleys at different levels. Each bed ends down stream in a precipice, hence there are several waterfalls in the region when the rains furnish water. Great quantities of gravelly débris and large and small bowlders have been carried down these water courses into the Rabaka by the floods which have traversed them since the eruptions removed the protective covering of vegetation and furnished an abundance of new loose material; but the stream beds are wider, the bordering material is the tuff agglomerate which tends to make a V-shaped section beside a degrading stream, and the U-shaped section has not been clearly developed.

The Wallibu and Rabaka River valleys are described and discussed more in detail in the following paper.

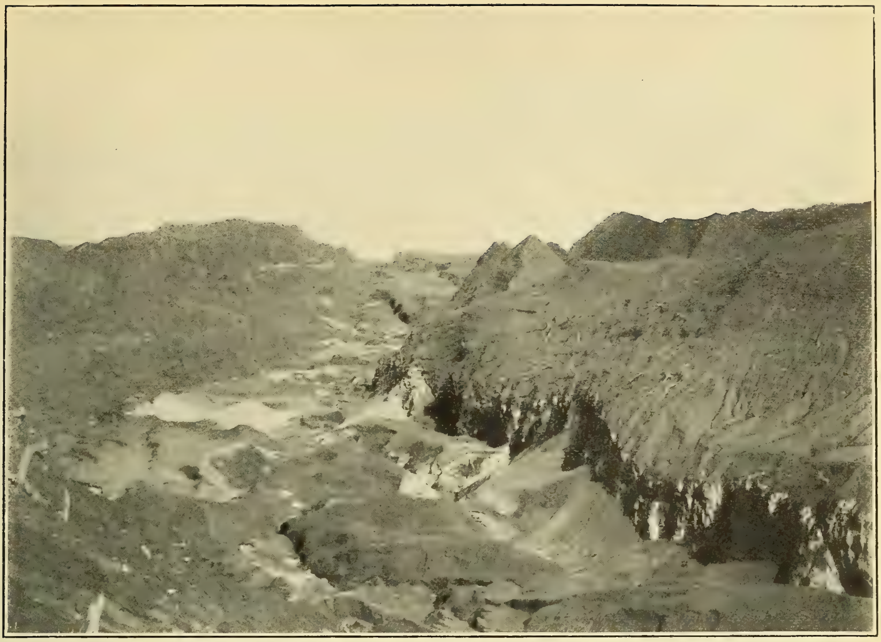

FIGURE 1.—ROSEAU VALLEY, SOUFRIÈRE, SAINT VINCENT

Ash-filled middle reaches, May 31, 1902

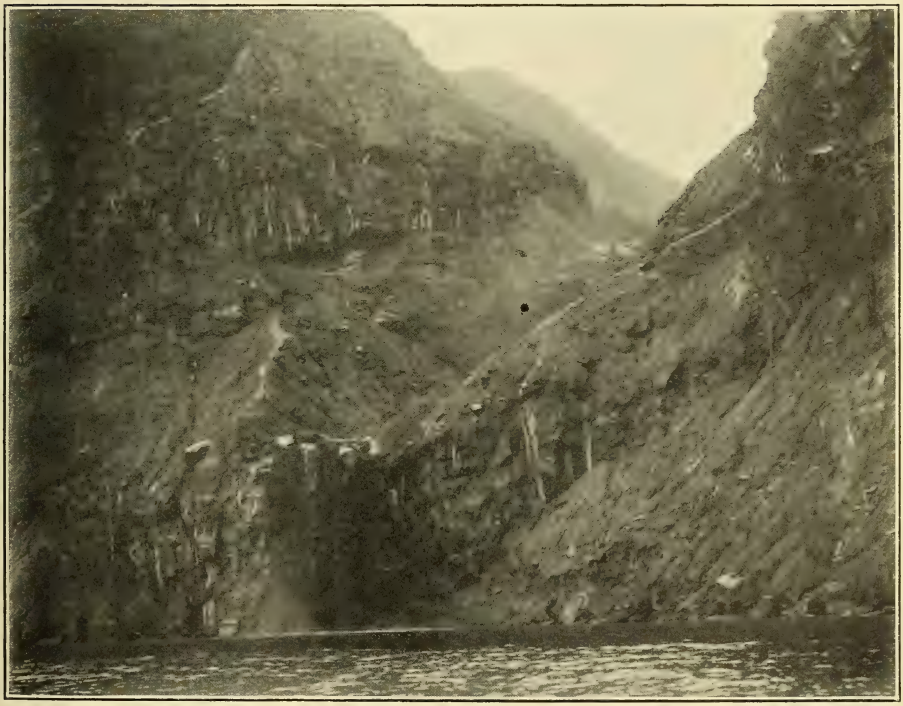

FIGURE 2.—MUD-FLOW FALLING OVER PRECIPICE INTO THE SEA

A "hanging valley" of the Soufrière

GORGES OF THE SOUFRIÈRE, SAINT VINCENT

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 20, PP. 417-426, PLS. 43-45 DECEMBER 31, 1909

CLEARING OUT OF THE WALLIBU AND RABAKA GORGES ON SAINT VINCENT ISLAND[1]

BY EDMUND OTIS HOVEY

(Presented orally before the Society December 29, 1908)

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INTRODUCTION

Interesting phases of the process of carrying to the sea the vast quantity of debris thrown out by a great volcanic eruption are shown by the history of the gorges of the Wallibu and Rabaka rivers, Saint Vincent, British West Indies, since May 7, 1902, when the volcano known as the Soufrière suddenly resumed violent activity. Practically the entire catchment basins of these streams were affected by the eruptions. The northern half of each lies upon the southern slopes of the volcano, and therefore felt the full force of the avalanches of débris and the blasts accompanying the rolling clouds of dust-laden steam. On these slopes the vegetation, including the big forest trees with few exceptions, was completely destroyed or swept away, together with most of the soil, and a deposit some meters thick of new ash was laid down on the ridges, while thicker accumulations formed in the valleys.

The southern halves of the basins lie on the northern slopes of the Morne Garu mountains, facing the crater. These received a thick mantle of ash, and the surface vegetation was mostly destroyed, though the vegetable mold and soil were not much disturbed, being simply buried.

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[1] Published by permission of the American Museum of Natural History.
Manuscript received by the Secretary of the Society August 30, 1909.

WALLIBU GORGE AND VALLEY

The immediate gorge of the Wallibu is bordered by bluffs ranging from 50 to 150 meters in height. Where the stream issued from the bluffs of solid old-land at the sea beside the Richmond estate the gorge is about 215 meters wide, as determined by pacing, and it gradually diminishes to less than 5 meters about 3 kilometers from the sea, where the permanent stream flows through a defile, the right bank of which was formed by agglomerate, the left by the edge of an old lava bed. The water filled the whole width of this defile, and was so deep and turbulent when I visited the spot (March, 1903) that I progressed no farther in my explorations of the bottom of the gorge. Above this point, however, the gorge widens out again.

It is impossible, perhaps, to estimate closely the amount of material deposited in the areas drained by the two rivers in question, but it is probably well within the bounds of fact to say that the average depth of the débris left in the Wallibu gorge was not less than 30 meters, while that in the gorge of the Rabaka was at least as great.[2] The depth of new material thrown into the side ravines was likewise to be measured by meters. The mantle of compacted dust (mud) along the southern rim of the crater and on the upper slopes of the mountain draining into the Wallibu was from half a meter to 2 meters in thickness in June, 1908, after the loss of material due to the erosion of six rainy seasons. There is every reason to suppose that as much or more ash covers the head slopes of the Rabaka, but no sections of the deposit were observed here in June, 1908. In June, 1902, however, Mr G. C. Curtis and I came near losing our way in gullies 2 to 4 meters deep in the new ash at the head of one of the tributaries of the Rabaka, and more ash was cast on the slopes in subsequent outbursts.

To one who has been over the ground an estimate of 5 meters will not seem excessive for the average depth of the ash over the "area of annihi-

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[2] The estimate of 200 feet for the depth of the filling of the Rabaka gorge, as given by myself (Bull. American Museum of Natural History, vol. xvi, p. 343) and Doctors Anderson and Flett (Philosophical Transactions of the Royal Society of London), were derived from the same source, a Mr A. H. Spence, of Saint Vincent, and seems to have been excessive. The vertical sections quoted in a later part of the present paper show the depth of the new filling to have been from 30 to 35 meters deep where the Rabaka issues from the hills. Farther up stream the deposit was somewhat deeper, but 40 to 45 meters seems to be the maximum that can be assigned to the original depth of the new débris thrown into the gorge by the 1902-1903 eruptions.

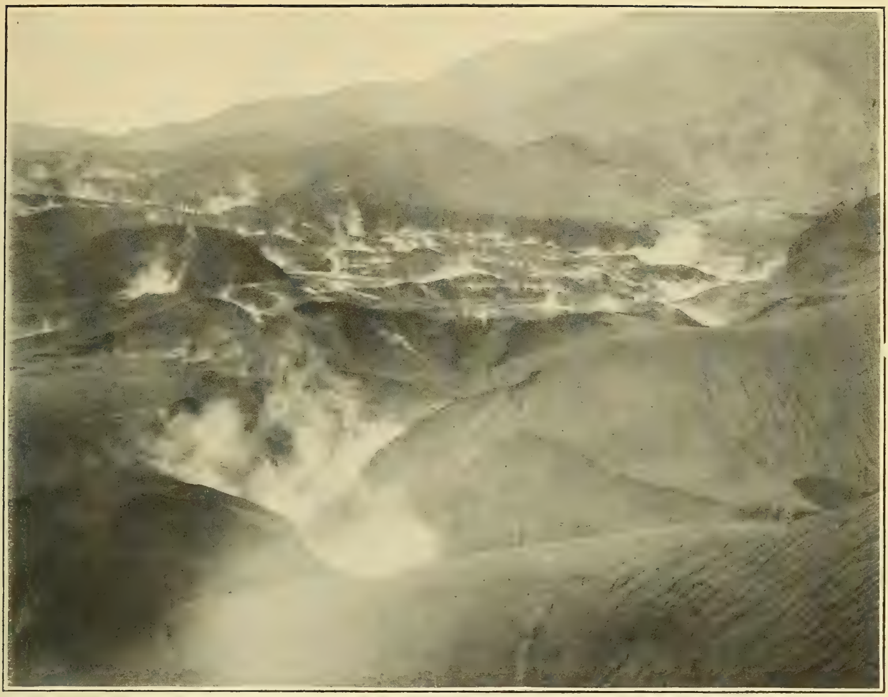

FIGURE 1.—WALLIBU GORGE, MAY 30, 1902

Nearly full of newly-fallen ash

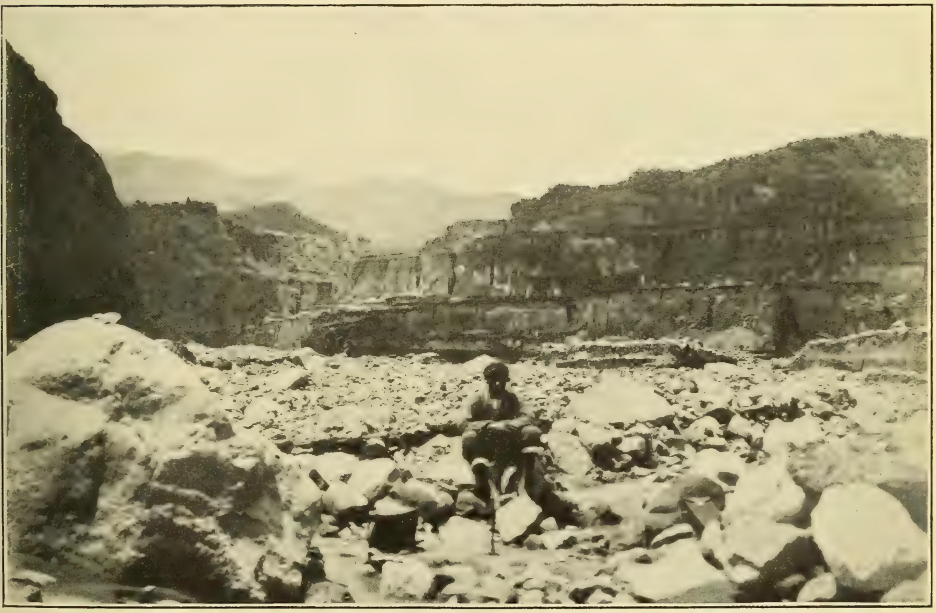

FIGURE 2.—WALLIBU GORGE, JUNE 18, 1908

Terraces show varying heights at which filling of new ash has stood

WALLIBU GORGE, SOUFRIÈRE, SAINT VINCENT

lation." This area was about 102 square kilometers (40 square miles), and on this assumption the amount of ash deposited on this restricted surface was about 510,000,000 cubic meters, or nearly one-eighth of a cubic mile. Reckoning the catchment basin of the Wallibu at one-tenth and that of the Rabaka at one-eighth of the area in question, we have 51,000,000 cubic meters as having been deposited in the former and 63,750,000 cubic meters in the latter. Guesses are hazardous, but it seems probable that at least one-half of this large quantity has been washed down from the slopes and carried into the sea. In 1903 I estimated[3] that not less than 5,500,000 cubic meters of ash had been washed out of the Wallibu gorge alone in the ten months from the beginning of May, 1902, to the beginning of March, 1903. Much more has passed out by the same route since.

Manner of Stream Work

The struggles of the streams with the débris began as soon as the eruptions deposited their loads. The rain from moderate showers sank at once into the mass of the ash and produced no other effect at first than to cause abundant explosions or secondary eruptions, as the water penetrated to the heated interior of the ash bed. From time to time these secondary eruptions were of imposing magnitude, one observed by Mr Curtis and myself on May 30, 1902, throwing its column of dust and mud laden steam to an estimated altitude of about 1½ kilometers.[4] I can not, however, agree with the hypothetical section proposed by Mr Curtis in the article to which reference is made or altogether with his explanation of the phenomena. His section[5] is faulty in that the gorge of the Wallibu does not have the V-shaped profile suggested therein, and the arrangement of material in it was not that assumed by him. As is indicated by figure 2, plate 43, the valley is broad in proportion to its depth (that is, in its lower courses—the portion under consideration) and is flat-bottomed, or nearly so. The present (1908) bottom is still 6 or more meters above the grade level reached before the eruptions; but the walls are nearly or quite vertical, and the breadth of this part of the valley is so great in proportion to the depth of ash still remaining in it that it is evident that no V-shaped section can be present here.

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[3] Comptes Rendus, IX Congrès géologique international, 1904, p. 729.

[4] Hovey: Preliminary Report, etc. Bull. American Museum of Natural History, vol. xvi, 1902, p. 343.

Curtis: Secondary phenomena of the West Indian volcanic eruptions. Journal of Geology, vol. xi, February-March, 1903, p. 200.

[5] Loc. cit., p. 211.

Furthermore, Curtis's figure represents the big fragments and bowlders as being concentrated in the bottom of his V-shaped gorge, to form a sort of accumulating region or channel for underground waters. This theory assumes that the big masses were thrown into the gorge first and the gravel and sand afterward, which can not have been strictly the case. Material of all sizes was thrown out together from the crater, and some sorting would naturally have followed deposition from clouds suspended in the air, but as a matter of fact the natural sections of the ash beds show that masses as much as 30 to 50 centimeters across were relatively scarce and scattered irregularly throughout the ash beds. Where they have reached the bottom of the gorge it has been mostly, at least, through being left behind on the removal of the finer material. The filling of the gorges was done for the most part by the rolling, sliding débris-avalanches that formed part of each great eruption cloud, in which there was little opportunity for assorting material according to size. Water sinks and flows more rapidly through coarse material than it does through fine, but the exposed sections of the new ash show the presence of enough irregular lenses of gravelly and bowldery material and clean sand to account for the repeated access of steam and rain water to the heated interior of the beds which was evidenced by the frequent violent explosions that were noted by all observers. With the gradient (3 to 4 degrees) still obtaining for the surface of the floodplain of the lower reaches of the Wallibu, the rapid stream 4 or 5 meters wide and about 1 meter deep that pours through the flat or possibly U-shaped gorge (rock-walled as to one side) of the upper reaches, ending about 3 kilometers from the coast, soon loses itself in the sand and gravel and pursues an underground course to the sea. The length of this subterranean flow varies up to about 2 kilometers, depending upon the volume of water in the stream. In June, 1908, it seemed to require a heavy shower of at least an hour's duration to bring the river down on its floodplain to the sea. After the stream bed became thoroughly saturated with water, comparatively gentle showers would keep the river running on the surface for many hours, perhaps for days. The tendency of the less important showers is to accumulate débris along the lower middle reaches of the stream bed, increasing the gradient of the flood-plain.

In the hollows of the original surface of the new ash bed, where its nature did not permit rapid percolation, but was favorable to the accumulation of water, pools were formed. These gradually enlarged until they coalesced, and the stream, struggling down from the hill slopes, found its way from one pool to another with varying vicissitudes. Occasionally a secondary eruption would throw a dam across the stream, impounding the

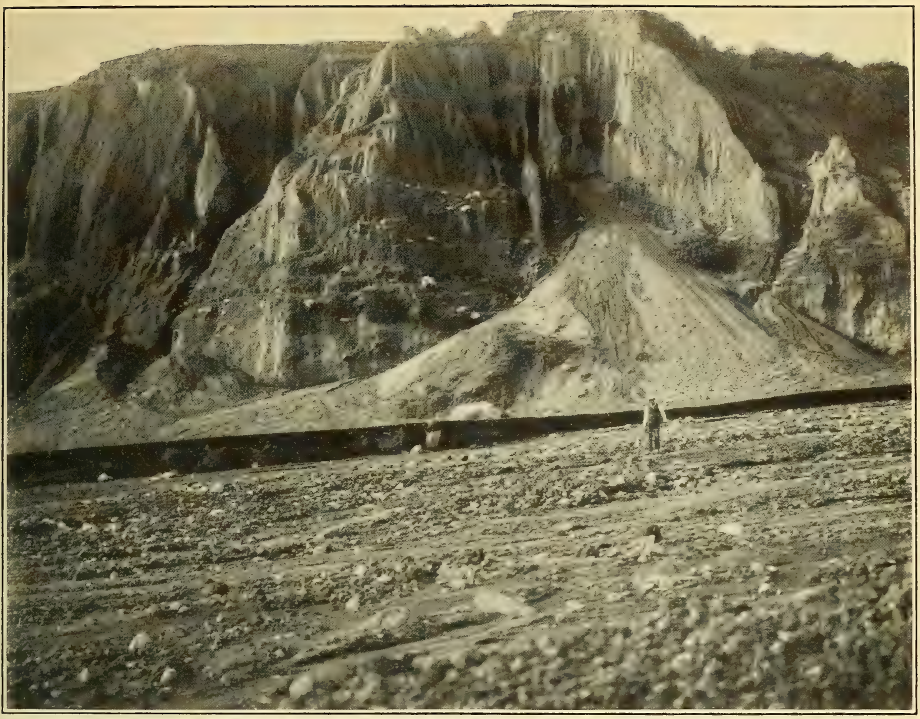

FIGURE 1.—ROSEAU VALLEY, SOUFRIÈRE, JUNE 19, 1908

Dust and sand cone showing dry landslides as method of bringing new ash within reach of a stream

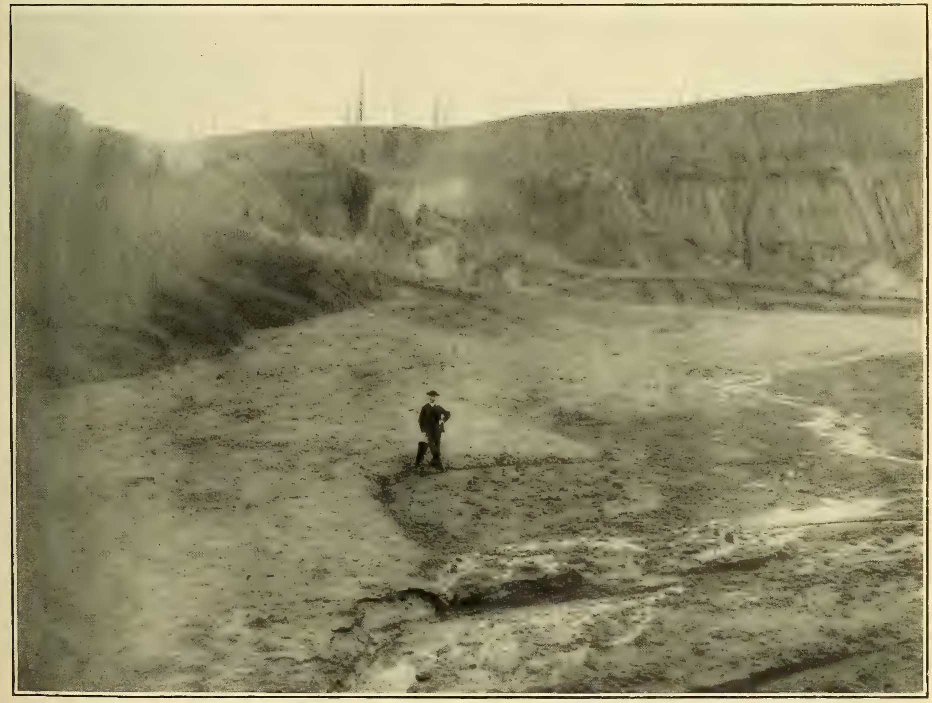

FIGURE 2.—WALLIBU GORGE, SOUFRIÈRE, MARCH 7, 1903

Dry, hot dust-flow resulting from a secondary eruption in the new ash

GORGES OF THE SOUFRIÈRE, SAINT VINCENT

water until the stream accumulated force enough to overcome its barriers, when it rushed down in pulsations to the sea. By the time of my second visit to Saint Vincent, in March, 1903, the immediate gorge of the Wallibu had been mostly cleared of its filling of ash, except for material retained in protecting curves of the walls, and a considerable amount of material had been washed off from the hill slopes. At that time hot, dry dust-flows were still carrying material out from the sides into the bottom of the gorge (see plate 44, figure 2), showing one method by which the dry season contributed to the removal of the fresh material. The general history of events has been that dust-flows during dry weather and the moderate showers of all seasons have brought material down into the gorge which the torrents due to heavy rains have carried out into the sea.

My third visit, in the latter part of June, 1908, was at the end of the dry season, when the effects of this filling process were quite evident. An immense amount of volcanic gravel and sand formed a comparatively high floodplain in the mouth of the gorge, and for half a kilometer or more inland from the line of coastal bluffs, ready to be carried out when the rainfalls should provide sufficient water for the purpose. One afternoon during this visit there was a downpour of rain lasting about two hours. This brought the river down on the surface of its bed to the sea in pulsations overloaded with débris, and easily rolling along bowlders 30 or more centimeters in diameter. The stream flowed in the form of waves 30 to 60 centimeters high, whose crests passed the point of observation every 10 to 12 seconds. Following each crest was slack water, with consequent deposition of sediment tending to change the course of the next crest and break it up into rivulets distributed over the broad expanse of the river bed. These pulsations were exactly like those noted in the Wallibu and Rabaka in May, 1902,[6] which evidently were not a function of either the primary or the secondary eruptions. Neither can temporary dams thrown across the streams by landslides, as postulated by Anderson and Flett, be considered their sole or even principal cause. The explanation advanced independently by Professor Russell and me received ample confirmation in June, 1908, when frequent showers brought the Wallibu and Rabaka rivers down in pulsating floods, though the volcano had been quiet for years; the thick beds of hot ash had largely or quite disappeared, and the gorge had widened so that landslides, become comparatively infrequent, could not possibly have any regularly intermittent effect on the streams. Our explanation was that the overloading of the streams with débris caused temporary periodic damming or checking of the water, the waves being due to the accumulated water overcoming the obstruction.

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[6] E. O. Hovey: Bull. American Museum of Natural History, vol. xvi, 1902, p. 344.
I. C. Russell: National Geographic Magazine, vol. xiii, 1902, p. 276.
Anderson and Flett: Philosophical Transactions of the Royal Society of London, series A, vol. 200, 1903, p. 430.

In June, 1908, the upper level of the floodplain of the Wallibu at the point where the river leaves the old lines of bluffs was about 5 meters above the level of the floodplain before the recent series of eruptions began, as was shown by its relation to a bit of old stone wall that, according to my guide, an intelligent black man, formed a part of the waterworks pertaining to the Wallibu sugar estate which was ruined by the eruption of 1812. The bluffs were about 215 meters apart at their bases, as determined by pacing. The vertical section of the new ash at this point, therefore, may be taken at 5 meters by 215 meters. About 2½ kilometers from the sea the river in June, 1908, just as in March, 1903, was flowing in its old channel in the decomposed ash. At this point the bed of the gorge is about 50 meters across.

The evidence of the successive stages in the reexcavation of the gorge is given in the terraces bordering the stream at several points. The best series of these, perhaps, is at a distance of about 2 kilometers from the sea (see figure 2, plate 43), where, in June, 1908, six terraces recorded the height to which each successive dry and moderately rainy season filled the gorge, and indicate the down-cutting due to each succeeding season of torrential rains, the "dry" seasons being periods of aggrading stream action and the rainy seasons being periods of degradation. The highest terraces probably indicate the level of ash filling due directly to the eruption clouds. The slope of floodplain and terraces near the sea was measured at 3, 3.5, and 4 degrees in the Wallibu and other gorges. The condition of affairs between the bluffs at the mouth of the Wallibu, when Doctor Anderson was there in the spring of 1907,[7] was completely altered by June, 1908. Doctor Anderson's beautiful photograph shows a broad terrace 9 meters high of water-sorted ash at the right (north) side of the gorge, and extending seaward beyond the bluff line, younger terraces appearing at lower levels on both sides of the stream. The stream was flowing along or near the left wall of the gorge. In June, 1908, there was not a trace of these terraces to be seen, all the material having been swept away, and when the stream flowed on the surface it occupied a channel at the immediate base of the great bluff forming the right wall of the gorge. Beginning just within the gateway formed by the bluffs and extending seaward for 200 meters more or less, there was, in June, 1908, a lenticular terrace perhaps 50 meters wide and three-fourths of a meter high. Doctor Anderson furthermore states that in the winter of 1906-1907 the river ran along the broad upper terrace which I have just described from his plate.

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[7] **Philosophical Transactions of the Royal Society of London, series A, vol. 208, p. 278, pl. 11.**

Leeward Shoreline

The chattering vibrations of the mountain due to friction of the eruptive mass ascending through the conduit of the volcano caused the coastal plain or apron from Richmond village northward for more than 5.5 kilometers to be shaken off into the depths of the sea. This apron seems to have been at least 100 meters wide in places—at any rate, the negro villages of Wallibu and Morne Ronde were located on it. At the time of my first visit, in May, 1902, the whole coastline was abrupt except where the larger streams discharged into the sea, and even at these points the under water slope seemed to be steep. The shoreline at the mouth of the Wallibu was almost straight, and was scarcely 50 meters beyond the bluff line of the Richmond and Wallibu estates. The river mouth was embayed 100 to 120 meters at this time, between benches of new and old ash whose tops were 20 to 22 meters above the sea. In March, 1903, the Wallibu had pushed the shoreline of its mouth nearly out to the points of these benches, while the benches themselves had lost some of their seaward extent through the action of waves and currents. The shoreline was still but slightly convex, and continued to be at right angles to the line of direction of the lower valley. In June, 1908, the shoreline was strongly convex and apparently 100 meters farther out than in 1903, while the northern bench had lost about half its 1902 extent through erosion by river and sea.[8] It was evident, furthermore, that much of the material brought down by the Wallibu had been spread along the coast northward by the marine currents. The history of the whole coast from Richmond village (just south of the mouth of the Wallibu) northward to Larikai point has been the same—the new or augmented headlands had been cut back by the waves, the deltas of the streams (Wallibu, Wallibu Dry, Rozeau, Morne Ronde, Trespé, and Larikai rivers) had been pushed out from 50 to 250 meters, a narrow strip of beach had been restored, increasing from nothing, or practically nothing, in May, 1902, to 40 or 50 meters in June, 1908. North of Larikai point the losses of the coast in May, 1902, were insignificant, if any were suffered, and the gains in the succeeding six years were correspondingly meager.

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[8] This statement is directly contrary to one made by Doctor Anderson in his supplementary report: "The fan of the Wallibu in 1902 extended beyond the coastline, and was very steep. Gushes of hot mud came down it, and tended continually to build it up. In 1907 it scarcely extended beyond the coastline, and both have receded considerably" (Philosophical Transactions of the Royal Society of London, series A, vol. 208, p. 281), but a careful study of my own and other photographs of the mouth of the Wallibu, together with my field notes, confirms me in holding to the statements made in this paper. No accurate survey of the region has been made, as far as I know, since the eruptions began.

RABAKA RIVER VALLEY

The history of Rabaka river on the windward (east) side of Saint Vincent presents an interesting variation from that of the Wallibu. The new ash filled the old gorge completely near the point where it issued from the hills,[9] with the result that a new gorge to the sea was cut, abandoning the old channel about 3 kilometers from the shoreline. The new gorge was speedily cut down nearly to grade level, and it discharged a large part of the burden of ash in the upper catchment basin of the stream. The new filling of the gorge, therefore, remains as a permanent change in the topography below the point where the new gorge branches off from the old. The Wallibu made a like change in its gorge after the eruptions of 1812, shifting its main channel from the north to the south side of the Wallibu plantation. This change is indicated by the topography and the chart, and note of it is preserved in the history or tradition of the island, according to Doctor Anderson.[10] Another permanent change in the drainage of the Rabaka was on the south side of the ash-filled gorge,[11] where ponded waters on the surface of the new ash finally, with the assistance of dams formed by secondary eruptions, cut a new gorge through the old wall of the river and ultimately opened a way for the escape of the drainage of a considerable portion of the old basin through that portion of the old Rabaka River channel, which extended from the foothills to the sea. New material has been spread out over the preeruption floodplain of the Rabaka in a mantle several meters thick. Where the Windward Side postroad crosses this plain, about 250 meters from the point of the new delta, the mantle is shown, by a ravine which has not yet cut its way down to grade, to be not less than 4 meters thick. Along this road the old floodplain measures about 450 meters wide. North of this old floodplain there is a narrow strip a few score meters wide of old coast sand, bearing the seagrape, and then comes the new floodplain of the Rabaka, formed since the eruption, which measures about 245 meters

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[9] Hovey: Preliminary Report, p. 343, pl. xxix, fig. 1.

[10] Philosophical Transactions of the Royal Society of London, series A, vol. 208, p. 279.

[11] Hovey: Comptes Rendus, IX Congrès géologique international, 1904, p. 729.

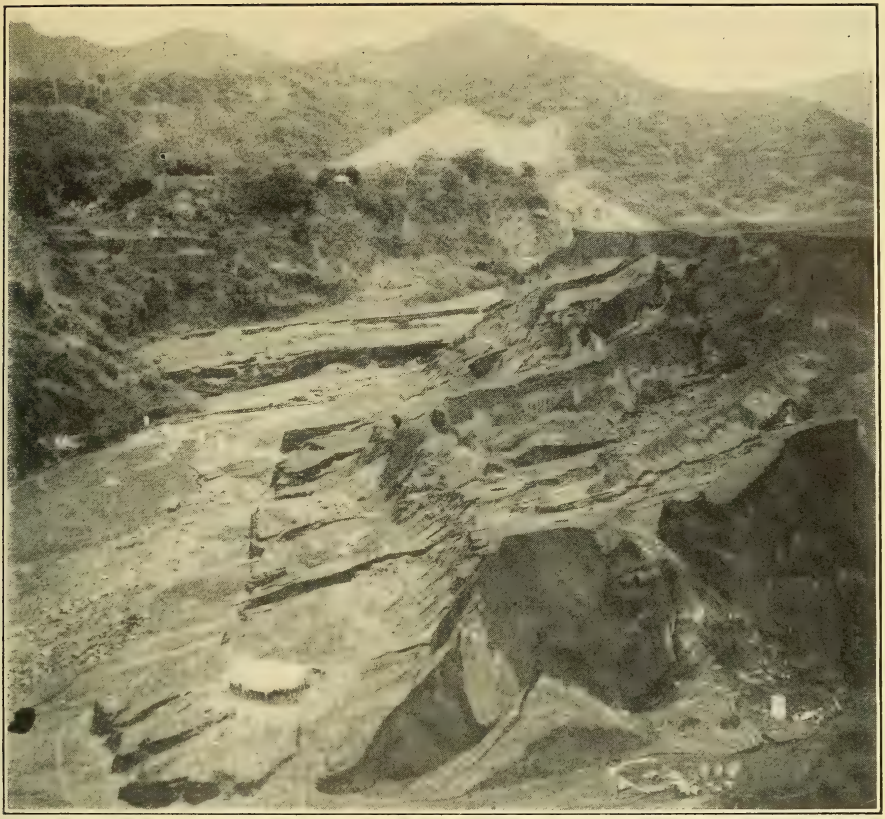

Figure 1.—Rabaka Gorge, June 26, 1908

Great bank of volcanic ash of 1902 eruptions is seen at right, trenched nearly to old grade level. Top shows approximately the maximum depth of the débris. Side of original gorge shows at left. Trunks of trees killed by the eruption rise above new growth on the hills.

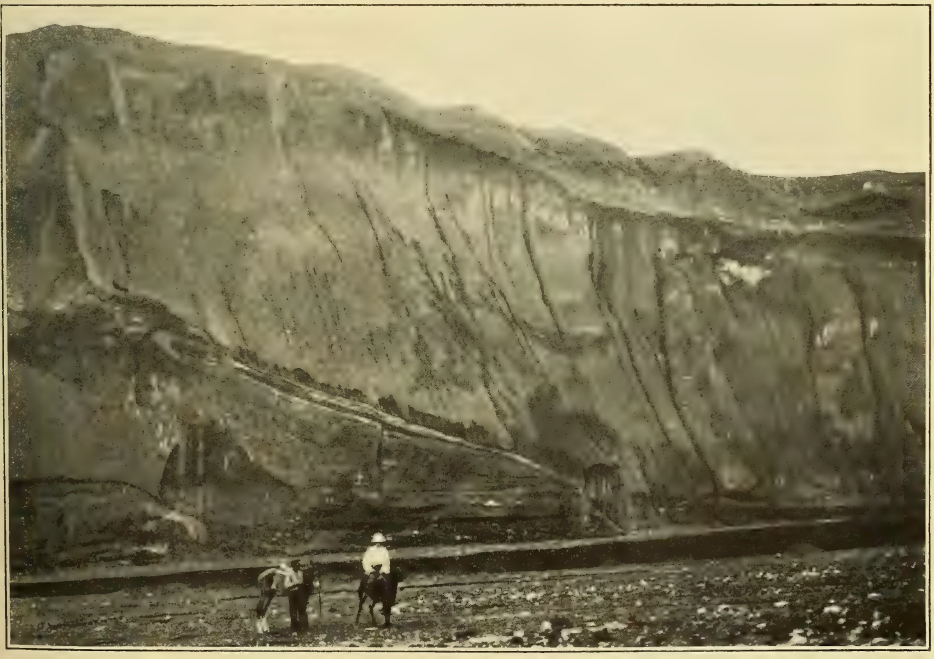

Figure 2.—Rabaka Gorge, June 26, 1908. Point of Departure of new Gorge from old

The oblique line in the bluff is the boundary between the old tuff agglomerate and the filling of new ash which changed the stream course

RABAKA RIVER, SOUFRIÈRE, SAINT VINCENT

along the postroad. In June, 1908, the main channel, dry except during floods, was beside the old Rabaka sugar and arrowroot mill, part of which had been carried out to sea by the torrents. This channel was 2 or 3 meters deep and 60 meters across. A few meters seaward from the postroad the new and old floodplains merged into one expanse 700 to 725 meters across, forming a new shoreline.

The ash that was cast into the Rabaka by the eruptions was coarser in grain and apparently more abundant in quantity than that which was thrown into the Wallibu; hence the middle reaches of the former have been much less thoroughly cleared out than those of the latter, but they show a similar succession of terraces. There are no statistics giving the comparative rainfall of the windward and the leeward sides of the island or of the mountain, so that it is impossible to state accurately which valley has had the more frequent showers or the greater amount of water to effect the transportation of the material. The catchment basin of the Rabaka, however, is greater than that of the Wallibu, and the windward side of the Soufrière-Morne Garu region probably receives a heavier rainfall than the leeward; hence, other factors being equal, the Rabaka gorge would have been reexcavated before the Wallibu, but the coarse gravel filling the Rabaka gorge allowed freer circulation of water than was possible in the fine sand and dust filling the Wallibu, and the larger, heavier grains required a greater quantity of water or velocity of stream to transport them. Furthermore, the clearing of the Rabaka was delayed by the necessity of cutting the new gorge already mentioned, though the excavation was carried on with great rapidity, once it was begun.

WINDWARD SHORELINE

Before the eruptions of 1902-1903 began the shoreline at the mouth of the Rabaka was essentially straight, according to the admiralty chart, it being evident that no more material was brought down by the floods of each rainy season than could be distributed by the currents during the succeeding dry months. The immense amount of débris brought down during and after the recent eruptions extended the shoreline at the mouth of the stream in a broad deltal fan some hundreds of meters into the sea, but it is not possible to state just how far, since I neglected to make measurements either in 1902 or 1903, and I have seen no mention of the matter in others' reports. In 1908 I made some measurements by pacing, and determined that the shoreline was still about 200 meters beyond the old strand near the new mouth of the Rabaka, presenting to the sea a low bluff 2 to 4 meters high, at the base of which was an apron, several meters broad, of bombs and other bowlders concentrated by the waves after they had washed out and carried away the finer ash that had been brought down by the torrents and floods of the river. Southward across the broad mouth of the old Rabaka the new shoreline receded slowly, but south of the river the coast was only slightly altered, though there was much fresh ash along the beach as far as Colonarie point and diminishing quantity south of there, varying with the amount of ash deposited upon the land. Colonarie point was nearly at the southern limit on the windward side of the damaging fall of ash. This limit ran irregularly in a general northwesterly direction across the island to and along the ridge bounding the Richmond valley on the southwest. South of this line the new ash did not seriously injure the vegetation, and therefore it remained practically where it fell, and has been washed but slowly to the sea.

North of the mouth of the Rabaka the conditions have been entirely different. The windward slopes of the Soufrière as far as Chibarabu point, 6 kilometers from the Rabaka, received a devastating quantity of ash, most of which, however, fell on the catchment basin of the Rabaka. The disposition of this has been discussed already. North and east of this basin the mountain slopes allowed the new ash to be washed rapidly to the sea through several small stream channels, but returning vegetation seems practically to have stopped this process. The gentle slopes of the cultivated plantations have retained practically all of the new material that was deposited on them.

From Colonarie point, then, northward at least as far as Sandy bay, just north of Chibarabu point, but particularly from the mouth of the Rabaka northward, vast quantities of new and some old ash have been distributed along the coast by the ocean currents, widening the beach by a few to many meters. It seems likely, however, that the waves and currents will continue their work till the preeruption coastline has been reestablished.

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PALEOGEOGRAPHY OF NORTH AMERICA[1]

BY CHARLES SCHUCHERT

(Presented before the Society December 30, 1908)

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[1] Manuscript received by the Secretary of the Society September 7, 1909.

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Introduction[2]

It is now nearly thirty-eight years since the writer found his first fossil at Cincinnati, Ohio, during the past twenty-four years of which he has devoted his entire time to invertebrate paleontology and Paleozoic stratigraphy. His professional service in these sciences had its initiative in association with E. O. Ulrich, and was continued with James Hall, C. E. Beecher, and Charles D. Walcott. Subsequently nearly all the larger American collections of Paleozoic fossils, as well as many European ones, have been examined or studied by him. For eleven years he had charge of the unrivaled collections assembled through the various government surveys, which are now deposited, together with much other material, in the United States National Museum. It was during these years of paleontologic abundance, grand library facilities, and the enthusiasm engendered through daily association with eleven paleontologists that he began the investigation of the problem of interprovincial correlations. The greatest stimulus toward determining the provincial value of fossils came in 1894, from reading Suess's celebrated work "Das Antlitz der Erde." Observations of the kind noted by Suess became sufficiently frequent by the year 1900, so that when Ulrich removed from Newport, Kentucky, to Washington, the inspiration of his presence, together with his detailed knowledge of the older Paleozoic periods, led to the publication in 1902 of "Paleozoic seas and barriers in eastern North America," this paper being the first joint expression on inter-regional correlations by Ulrich and Schuchert. From this time on, and especially since his appointment at

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[2] Teachers and others may obtain of the writer, at cost, copies of the paleogeographic maps as here printed, as well as of two types of blue-prints of the original maps, size 20 by 26 inches; also lantern slides.

Yale University, the present writer's efforts have been largely devoted to the paleogeography of North America. Fifty-seven paleogeographic maps have been made and fifty-two are here published, nearly all American sources of geologic literature having been ransacked for information. In presenting this work to his collaborators, the writer feels impelled to state that he is fully aware of the imperfection of these maps, but they are now issued for the purpose of furnishing something tangible on which to work. To continue these studies, and thus be enabled to offer later an improved and larger series of maps, is the hope of the writer, who asks the cooperation of all paleontologists and geologists toward this end.

While the maps were in process of construction the underlying principles thus brought out were frequently discussed with Professor Barrell, of Yale University, and from time to time the maps themselves were labored over with Ulrich and Stanton. At the Baltimore meeting of the Geological Society of America most of the maps were shown, since which time the seas plotted on them have undergone many a surgical operation at the hands of Canadian and American geologists. During April, 1909, a week was profitably spent in Ottawa, where the maps were much improved by suggestions made by the geologists Ami, Ells, Dowling, McConnell, Fletcher, Faribault, McGinnis, Keele, and Lowe, while later two weeks were devoted to the same end by the paleontologists of Washington—Ulrich, Stanton, David White, Knowlton, Dall, Walcott, Arnold, Vaughan, Kindle, Bassler, and Breger—a day being finally given to them by Clarke at Albany, New York. Berry, of Johns Hopkins, also helped. Much information in regard to the geology of Alaska was obtained of Brooks. For other areas direct assistance was had of Ransome and Mendenhall.

To all these gentlemen, to Messrs W. H. Twenhofel and J. A. Larsen, and Miss Lucy Peck Bush, of the graduate department of Yale University, the writer desires to express his sincere thanks, which are also due to the various geologists who have worked out the geology of the North American continent and whose publications have given valuable aid in the present investigation, though but few of the authors' names are mentioned in the text. For the benefit of those persons who may not be familiar with this voluminous literature pertaining to the geology of this continent, the following indispensable catalogues are here cited:

Darton: Catalogue and index of contributions to North American geology, 1732-1891. Bulletin 127, U. S. Geological Survey, 1896.

Weeks: Bibliography and index of North American geology, paleontology, petrology, and mineralogy for 1892-1900. Bulletins 188 and 189, U. S. Geological Survey, 1902.

Weeks: Bibliography and index of North American geology, paleontology, petrology, and mineralogy for 1901-1905, inclusive. Bulletin 301, U. S. Geological Survey, 1906.

Weeks and Nickles: Bibliography of North American geology for 1906 and 1907. With subject index. Bulletin 372, U. S. Geological Survey, 1909.

Dowling: General index to the Reports of Progress, Geological Survey of Canada, 1863-1884. Published in 1900.

Nicolas: General index to Reports, Geological Survey of Canada, 1885-1906. Published in 1908.

HISTORY OF PALEOGEOGRAPHY

DETAILED REFERENCES

In his presidential address before the Geological Society of London, in 1881 (page 203), Robert Etheridge introduced the term "paleogeography," this being apparently the first time the word was brought into use. However, as the expression is so closely allied in thought with ancient geography, it may have had an earlier origin. Since Canu's use of the word in 1896, it is frequently seen in print, and is now generally adopted to signify the geography of geologic time.

The earliest paleogeographic maps indicating the ancient relation of seas to lands may be attributed to James D. Dana. In the first edition of his "Manual of Geology" (1863), three maps are given showing respectively the "Azoic lands and seas of North America" (136), "North America in the Cretaceous period" (489), and "North America in the period of the early Tertiary" (530).

In 1865 Heer's famous book, "Die Urwelt der Schweiz," appeared at Zürich, and in it were presented four paleogeographic maps of central Europe during the Jurassic, Cretaceous, and Middle Miocene. These maps are detailed, and agree with modern ones in recognizing that the continental seas are local bodies of water between small land-masses.

In 1866 a high grade paleogeographic map made by Goodwin-Austin[3] was published in England, and showed the lands and seas during Crag or Pliocene time. Ten years earlier,[4] however, the same geologist had printed what may be regarded as a paleogeographic map exhibiting the probable lands of western Europe during Paleozoic and Mesozoic time. This seems to be the first paleogeographic map, but as it treats of no specific time—the author himself so states—the priority apparently belongs to Dana.

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[3] Quarterly Journal of the Geological Society of London, vol. 22, 1866, p. 240.

[4] Ibidem, vol. 12, 1856, plate 1.

In the second (1874) and third (1880) editions of his Manual, Dana's three maps of 1863 remained practically unchanged, but in the fourth edition (1895) six new and much improved maps are presented. An analysis of these shows that they are not based on a limited time, but are composite maps of an entire system; further, that the seas are made to spread over vast portions of the North American continent, where no rocks of the system under consideration are known even at the present day. This idea of "universal oceans" is forcibly brought to one's attention in Dana's map of the Siluric—a time, as will be shown later, when not only vast areas of the continent were above the sea, but during which there was also an irregularly progressive submergence followed by a widespread elevation. Moreover, these maps do not take into account the various and distinct contemporaneous faunas, each of which is restricted to a limited region. If, as depicted by Dana, the broad Siluric ocean is to be accepted without intermediate land barriers, these faunas should then have a universal expression, which, as paleontologists know, is not the case. However, Dana's maps bring out clearly his widely known hypothesis of the gradual emergence of the North American continent and the progressive accretion of younger and younger deposits around his great Laurentian V—the nucleus of North America. Only in the most general way can agreement be had with this hypothesis, for it will be seen that the sea transgresses often and widely over the earlier accretions to the North American nucleus.

In 1883 the Austrian philosophical paleontologist Neumayr published his celebrated paper "Ueber Klimatische Zonen während der Jura und Kreidezeit," which includes what is probably the first paleogeographic map of the world. Here, again, no definite time is represented, the map being a composite picture of all the Jurassic. After more than thirteen years of study on the Jurassic ammonites, Neumayr here announced the distinct principle of localized and widely distributed marine faunas that appear to be arranged in *homoiozoic* or parallel belts due probably to zones of different temperature. On the basis of this distribution of marine Jurassic fossils he conceived the great transverse continent of Gondwana—a continent that has since become reduced to the present India, Africa, and South America. He likewise was the first to point out the fact that in all probability during Jurassic time there were climatic or temperature zones very similar in position to the temperate and tropical belts of today, yet no Permic nor Cambric tillites and scratched grounds had then been discovered.

The Irish geologist Hull[5] published three paleogeographic maps of Archean, Siluric, and Carbonic time, showing a great continent in the North Atlantic that furnished the sediments for the Paleozoic formations of western Europe and eastern North America. This he inappropriately called Atlantis. It is a striking fact that all paleogeographers dealing with the North Atlantic region have indicated this great transverse land variously known as Laurentia, Arctic, Greenland, Atlantis, North Atlantis, Great Northern continent, Nearctis, and Old Red continent. It is the Paleozoic and Mesozoic equivalent of Gondwana, the continent equally extensive in the southern hemisphere.

In the three editions of his "Geological studies," published between 1886 and 1889, Alexander Winchell presented six paleogeographic maps that show far more emerged land, usually as islands, than the maps of Dana; but in these also are indicated the widespread, freely intermingling waters of a vast continental sea which, if really existent, would have produced universal faunas.

The first geologist to put forward a series of maps showing the progressive geologic geography of a given area was Jukes-Brown, who in his volume entitled "The building of the British Isles: A study in geographical evolution" (London, 1888) included fifteen such maps. This represents the earliest extended work on ancient geography consistently wrought out on the basis of the distribution and the petrologic character of the geologic formations and their deformations. His principles are not widely different from those of Willis,[6] but his point of view is that of an areal geologist who does not attempt to understand the significance of the entombed fossils nor the detailed stratigraphy, but selects out of each system of rocks the widely distributed formations illustrating the growth of the British Isles. His maps show repeated irregular inundations of Great Britain from the east and the gradual disappearance of the western land into the Atlantic.

The most important book of reference dealing with paleogeographic maps is undoubtedly Lapparent's Traité, which has now become the standard work for maps of this kind. In the fourth edition (1900) of this well known treatise are included twenty-two maps of the world on Mercator's projection, thirty of Europe, twenty-one of France, together with ten taken from the works of other authors. The fifth edition (1906) presents twenty-three maps of the world on a stereographic projection, thirty-four of Europe, twenty-five of France, and ten from other authors.

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[5] Hull: Royal Dublin Society, 1885.

[6] Willis: Journal of Geology, Chicago, vol. 17, 1909.

Arldt[7] has brought together a vast mass of paleontologic and biologic information, which he has directly applied to the development and connections of the ancient continents. In his unique book, "Development of continents and their life," he reproduces seven paleogeographic maps of the world by Frech and Koken and adds three of his own.

"Antlitz der Erde," the famous book by Suess,[8] is of course indispensable in all paleogeographic work, and is now readily accessible in the English translation by Sollas and Sollas.

In his interesting and valuable work, "Archhelenis und Archinotis" (1907), Von Ihering discusses the various ancient lands of which South America is composed, and gives a paleogeographic map of the world in Eocene times.

In 1896 Canu[9] brought out an atlas of fifty-seven maps illustrating the ancient seas and lands of France and Belgium. Koken,[10] in his well known text book, gives four world maps of Cretacic and Cenozoic times. In 1907[11] he also published a large and most interesting map of the world in Permic time. Frech[12] (1897-1902) has shown six paleogeographic maps of the world during the Paleozoic era. Karpinsky[13] (1896) gave fourteen maps of European Russia, from the Ordovicic to the Pleistocene, inclusive. Ortmann[14] discusses the "Theory of Antarctica," and gives a paleogeographic map of that continent, with its supposed former land connections. D. White[15] (1907) enters into an interesting discussion in regard to the climate of Gondwana and the floral distribution obtaining there.

Chamberlin and Salisbury, in their "Geology" (1906), brought out eighteen North American maps of great value because of the careful plotting of surface outcrops and indications of the probable extent of the seas. These maps have been of considerable service in the present work.

Regarding the fifteen maps shown at the Baltimore meeting of the Geological Society of America, Willis[16] is publishing them while this paper is printing. These North American paleogeographic maps are excellent as far as they go, but they are too synthetic—that is, as a rule they embrace too much time, and hence do not bring out the oscillatory nature of the continental seas. Willis concedes the validity of the criticism "that each individual map covers so long a period of time and such diverse conditions that they do not truly represent any special geographic phase of the continent" (p. 204).

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[7] Arldt: Die Entwicklung der Kontinente und Ihrer Lebewelt, 1907.

[8] Suess: Antlitz der Erde, I, Abt. 1, 1883, 2, 1885; II, 1888; III, 1901; III, Abt. 2, 1909. The first two volumes translated into English by Sollas and Sollas, 1904 and 1906.

[9] Canu: Essai de Paléogéographie. Paris, 1896, text and atlas.

[10] Koken: Die Vorwelt und ihre Entwickelungsgeschichte, 1893.

[11] Koken: N. Jahrb. Min. Geol. Pal., Festband, 1907, pp. 446-546.

[12] Frech: Lethæa geognostica, 1897-1902.

[13] Karpinsky: Bull. l'Acad. Imp. des Sci., St. Pétersbourg, 1894. Also Ann. Géographie, Paris, 1896, pp. 179-192.

[14] Ortmann: Princeton University Expedition to Patagonia, vol. IV, 1902, pp. 310-324.

[15] White: Journal of Geology, Chicago, vol. 15, 1907.

[16] Willis: Ibidem, vol. 17, 1909.

These maps were made on the following basis:

> "A certain period having been selected as that which should be mapped, the epicontinental strata pertaining to that time interval have been delineated. The phenomena of sedimentation and erosion have been correlated, with a view to determining the sources of sediment and topographic conditions of land areas, and from these data the probable positions of lands have been more or less definitely inferred. Thus, certain areas within the continental margin are distinguished as land or sea, and these areas may be defined as separate bodies or connected according to inferences based upon isolated occurrences or upon later effects of erosion.
>
> "It is assumed that the great oceanic basins and such deeps as the Gulf of Mexico and the Caribbean have been permanent features of the earth's surface at least since some time in the pre-Cambrian" (page 203).

These principles have also governed the present writer in the following investigation. He has likewise been able to unearth a vast amount of paleontologic knowledge buried in American geologic literature, and during the past thirty years has gained wide experience in the field and the laboratory. The results thus attained have been freely discussed with many men, geologists as well as paleontologists, and the writer believes that by "selecting narrower time limits and more precise correlations than have been attempted" by Willis, he has taken at least "one of the steps in the advancement of knowledge" (Willis, 1909, page 204).

Walcott[17] has a "Hypothetical map of the North American continent at the beginning of Lower Cambrian time." In the same year[18] appeared another paleogeographic map portraying "the beginning of Ordovician time." Three very small maps, also representing Lower, Middle, and Upper Cambric times in North America and ascribed to Walcott, may be found in Lapparent's Traité. Walcott[19] has likewise brought out a valuable "Hypothetical map to illustrate the areas of the Cordilleran, Mississippian and Appalachian seas." Logan[20] has given an excellent map indicating the outlines of the late Jurassic continental sea, with North Pacific connections. As this sea is an independent one, it is named by the present writer Logan sea.

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[17] Walcott: Bull. U. S. Geological Survey, no. 81, 1891, plate 3.

[18] Walcott: Twelfth Ann. Rep. U. S. Geological Survey, 1891, plate 45.

[19] Walcott: Proc. Amer. Assoc. Adv. Sci., vol. 42, 1894.

[20] Logan: Journal of Geology, Chicago, 1900, p. 245.

Berkey[21] has given two maps showing the position of Mississippian sea during "mid-Saint Peter time" and at the "close of Saint Peter time." Grabau[22] shows one map of Cambric and four maps of Ordovicic time in North America. G. F. Matthew[23] portrays two maps—one of Lower Huronian, the other of Siluric time. W. D. Matthew[24] presents six good Tertiary paleogeographic maps of the world. Schuchert[25] published two Middle Devonic maps of eastern United States, and in 1908[26] presented three paleogeographic maps of the North American Devonic. Scott brought out eight paleogeographic maps of North America in his "An Introduction to Geology," 1907. Weller[27] indicated on two maps the probable shorelines within the United States of the latest Devonic and Osage of Mississippic time. The same paleontologist[28] published two excellent maps of the American Siluric shorelines and the Arctic path for these European faunas. Williams[29] presents a "chart showing the approximate position of the Devonian intercontinental sea." Veatch[30] exhibits ten maps of the land and water areas in the south-central United States during Cretacic and Tertiary times. Clarke[31] gives two Lower Devonic maps of New York.

RÉSUMÉ

By tabulating these maps, it will be seen that since 1863 no less than 306 different paleogeographic maps have been published, of which 151 relate more or less directly to North America. These maps are as yet highly hypothetical, this being particularly true of world maps.

The changes wrought in these maps are fundamental. Instead of the "universal oceans" of the older maps, modern ones show much smaller and more local seas, separated from one another by land barriers. Also may be noted the irregular emergence of local lands that are repeatedly submerged, the general tendency, however, being toward more stable continents and oceanic basins. The local seas, first mapped by Heer, may be seen to best advantage in Lapparent's most valuable Traité. Very few of the maps, however, as yet clearly differentiate between marine and continental deposits, and by the inclusion of both as marine deposits the continental seas are not only enlarged, but seas are even brought into existence where none whatever occurred.

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[21] Berkey: Bull. Geological Society of America, vol. 17, 1906, pp. 248-249.

[22] Grabau: Journal of Geology, Chicago, vol. 17, 1909.

[23] G. F. Matthew: Bull. Natural History Society of New Brunswick, vol. 6, 1908.

[24] W. D. Matthew: Bull. American Museum of Natural History, vol. 22, 1906.

[25] Schuchert: American Geologist, 1903.

[26] Schuchert in Eastman, Iowa Geological Survey, Ann. Rep., vol. 18, 1908.

[27] Weller: Journal of Geology, Chicago, vol. 6, 1898, pp. 307-308.

[28] Weller: Ibidem, 1898, pp. 697, 699.

[29] Williams: American Journal of Science, vol. 3, 1897, p. 395.

[30] Veatch: Professional Paper, no. 46, U. S. Geological Survey, 1906.

[31] Clarke: Memoir no. 9, New York State Museum, 1908, pp. 8-9.

METHODS OF PALEOGEOGRAPHY

CLASSIFICATION OF METHODS

The methods or principles for determining the relation of ancient seas and lands are four in number: (1) The Paleontologic, (2) the Areal-Geologic, (3) the Petrologic, and (4) the Structural or Diastrophic.

PALEONTOLOGIC METHOD

Basis of chronology.—The primary basis for a geologic chronology is furnished by the organic remains entombed in the stratified rocks. All methods for the exact determination of geologic time are at present dependent upon paleontology, yet it is not to be denied that locally other means than the paleontologic may become of prime importance.

Continental deposits.—There is as yet no established petrologic method whereby marine deposits can be distinguished from those of fluviatile or lacustrine waters. Fossils, therefore, are of vital importance in determining whether a sedimentary deposit (1) is derived from waters of the land deposited on the land—that is, a continental deposit—or (2) is of terrestrial origin, but laid down in marine waters. The physical nature alone of some formations renders their fresh-water or eolian origin fairly certain. When with these characters are combined the lessons to be learned from the entombed fossils, then the evidence is convincing.

The Triassic sandstone of the Connecticut valley consists of deposits which have been termed estuarine and fluviatile. They are better exposed and more extensively quarried in Connecticut than any other formation, and have been explored by geologists and paleontologists for more than a century, but not a trace of a marine animal has thus far been discovered. Evidence equally as strong was available twenty years ago, yet Dana taught that these sandstones were laid down in an estuary like that of the bay of Fundy. If this were true, marine fossils would have often been brought to light. On the other hand, indications of land plants and land animals are frequently met with, the most abundant being the footprints, or autogrammes, as Newberry called them, of quadrupedal, but mainly of bipedal, terrestrial reptiles. After being persistently collected, these tracks were described, first by E. Hitchcock, later by C. H. Hitchcock, while recently this subject has been restudied by Professor R. S. Lull,[32] who has determined 40 genera and 92 species. These impressions are all autogrammes of vertebrates living on the land. Of dinosaurs, there are certainly 17 species of Theropoda, with 18 of Predentata, to which may be added 27 other species that are probable representatives of this order. Of the bipedal carnivorous dinosaurs, three skeletons have been found (*Anchisaurus colurus, A. solus,* and *Ammosaurus major*); also, in addition to *Belodon,* two other crocodilian skeletons of quadrupedal land reptiles (*Stegomus longipes* and *S. arcuatus*). In the black shales between the extensive trap sheets occur many ferns, equisitales, cycads, and conifers, besides ganoid fishes and the larva of a neuropterous insect—an assemblage that can be interpreted only as that of inland fresh waters. None but animals and plants that inhabit the land are here seen, and when these are considered in connection with the exceedingly common sun-cracked layers of mud, less frequent raindrop impressions, local accumulations of semi-rounded boulders, and the nearly constant lens-shaped bedding of the imperfectly assorted sands and conglomerates between the muddier layers of wider areal extent, the evidence is positive that the Newark series is fluviatile in nature and must be eliminated from marine deposits and Triassic seas.

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[32] Lull: Memoir of the Boston Society of Natural History, vol. 5, 1904, pp. 461-557.

The writer has purposely dwelt at length on the Newark formations, because similar beds are found at many horizons, and until recently these have been regarded as of sea deposition. They must be eliminated from marine deposits, however, and referred to the land, and will thus at times very decidedly affect paleogeography. When continental deposits alternate with marine horizons, as is especially the case during Pennsylvanic time, such formations will naturally be mapped as marine. For a full discussion of the areas of deposition and the internal structure of continental deposits, see Barrell.[33]

Continental seas are shallow.—It is very probable that a majority of the periodic inundations of the North American continent resulted in very shallow seas, perhaps rarely exceeding from 200 to 300 feet in depth. In the discussion on later pages of this article, it is held that the continent is a horst, that the great medial region remained practically unmoved, while the margins were often folded and elevated. The sea periodically flowed over this medial land—in fact, was elevated over it, owing to the detrital materials unloaded into the oceanic areas, thus filling them and causing them to spill over on to the lands.

Along the western shorelines of Appalachia, conglomerates, sandstones, and coarse muds bearing ripple-marks are constantly met with, while during periods of calcareous deposition there is much evidence of shrinkage cracks on extensive mud flats that have been subjected to periodic inundations of calcareous material nearly devoid of life. These Paleozoic shores of Appalachia were not unlike the coral tidal flats of present Antillia. In the New York basin, most of the later Paleozoic deposits are those of estuaries, for the material is mainly sands and muds practically lacking in marine life. Here and there occur land plants, Old Red fishes, and occasionally fresh-water bivalves. Often the sands are red, oxidized, the estuaries of extensive rivers dried out by the sun and air. In the Ohio basin, but more particularly in the Indiana basin, where the adjacent lands were very low, more often occur similar widespread beds indicative of shallow seas. Such are the thin bedded limestones in alternation with shales, dolomites, oolites, and calcareous shales. Here may also be seen ripple-marks and shrinkage or sun-cracks. Along Appalachia and Laurentia are occasionally found salt and gypsum horizons, while in the late Pennsylvanic seas of Oklahoma occur alternations of red shales with thick beds of gypsum. The intraformational conglomerates further point to shallow agitated seas.

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[33] Barrell: Journal of Geology, Chicago, vol. 14, 1906, pp. 316-356, 430-457, 524-568. Ibidem, vol. 16, 1908, pp. 159-190, 255-296, 363-384. Bull. Geological Society of America, vol. 18, 1907, pp. 449-476.

The superficial depth of the continental seas is also reflected in the endless formational names, based on petrologic change, which have been proposed by the areal geologists. For further discussion of this subject, see the paper by Ulrich elsewhere in this volume.

Fossils indicative of exact time.—Most paleontologists are now aware that fossils can be relied upon to determine not only the broader units of time, but horizons of considerable areal extent, with but a few feet of thickness as well. Elsewhere in this volume Ulrich introduces remarkable examples of thin horizons that may be identified by a few fossils scattered over vast regions. This clearly indicates the increase in paleontologic knowledge since the days of Strata Smith's teachings, and today in America stratigraphic results are more easily attained because of the wide extent of successive undisturbed formations. Geological faunas within given provinces practically appear instantaneously, and intercontinental correlations based on faunule identities—that is, a combination of several species, in most cases, will probably not be out of synchrony more than from 10 to 20 feet. The evidence for these statements is discussed elsewhere by Ulrich.

It is now not always necessary to possess large collections of fine material in order to make correlations or to identify horizons of limited zones, a single fossil often being sufficient for this purpose. Brachiopoda and Bryozoa are usually to be found in the Paleozoic and are the finest horizon markers. In the Cincinnati series, *Catazyga headi* determines a zone in the Lower Richmond formation never more than one foot thick. *C. erratica* is always diagnostic of the eastern Lorraine. *Triplecia ortoni* is restricted to a limestone zone, never more than 25 feet in thickness, extending from Oklahoma to Ohio, while a closely related species occurs in a similar zone on the island of Anticosti in the Saint Lawrence gulf. The higher Clinton, from Anticosti to Alabama, may be determined by a single brachiopod, *Anoplotheca hemispherica,* which also identifies a very similar horizon in northwestern Europe. *Rhynchotrema capax* in two varieties defines the Richmond formation from El Paso, Texas, to Manitoba, and from the Big Horn mountains to Ohio, and even to Anticosti. *Spirifer hungerfordi* denotes the Upper Devonic throughout western America, from the Arctic to Bisbee, Arizona, and in Asia and Russia as well. These are not exceptional cases, and many more can be cited. When fossils are carefully collected from bed to bed, it is nearly always found that certain combinations of species called *faunules* may be depended upon to indicate unvarying zonal or time values within a subprovince. Sometimes the latter is of very wide extent, as in the case of the Upper Richmond formation just mentioned, while in other cases they are greatly restricted. As a rule, the more common species can not be relied upon for the determination of limited horizons, especially the ubiquitous plastic forms among brachiopods. For instance, *Atrypa reticularis, Leptæna rhomboidalis, Dalmanella testudinaria, Plectambonites sericeus, Rafinesquina alternata, Pentamerus oblongus,* etcetera, have little value for interprovincial correlation, and none at all when loosely identified, as is the almost universal practice among paleontologists.

Correlation between provinces is far more difficult, but when large collections are at hand the general faunal facies, together with a few identical or closely related species, will usually enable a paleontologist to fix upon a fairly definite time. Exact correlation that may be proved becomes impossible only in newly discovered areas, as is the case at present for Alaska. Even there, however, the faunas are now taking on determinable provincial relationship with those farther south.

Barriers.—In the United States there are often two or more provincial faunas of the same geologic age, apparently having geographically continuous strata that are wholly different, there being but few species common to them. As an example may be cited the Middle Devonic coral faunas in Kentucky, Indiana, Ohio, New York, Ontario, and Hudson bay. Contrasting this well known assemblage with the less abundant coral representation in Iowa and Missouri and in the entire country west to the Pacific, it is seen that while there is a time expression common to both provinces, there are practically no identical species. The eastern assem-

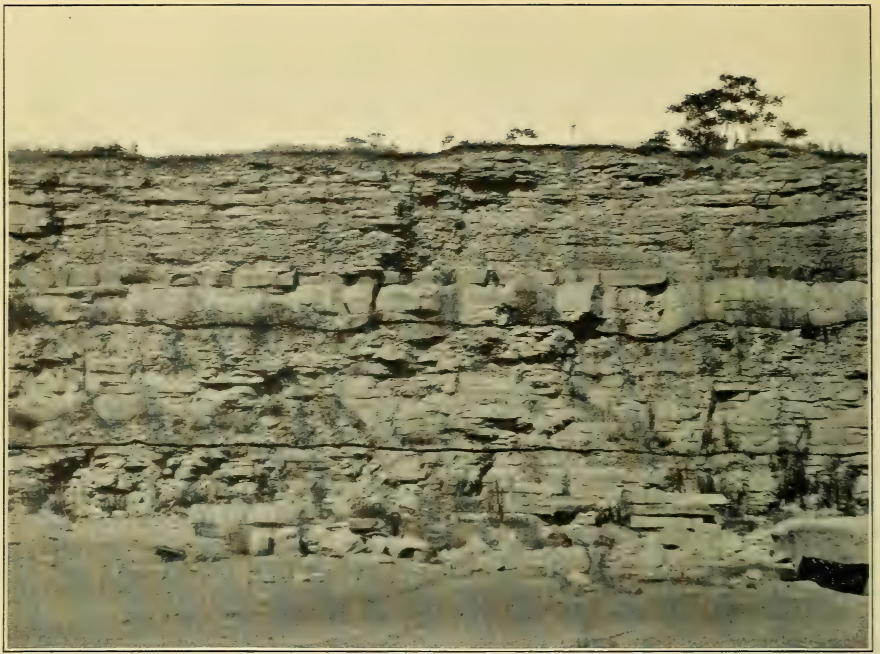


FIGURE 1.—QUARRY OF BENNETT CEMENT AND QUARRY COMPANY, BUFFALO, NEW YORK

Upper 8 feet Onondaga limestone (Lower Middle Devonic), resting on eroded Cobbleskill (Manlius of Siluric), which in turn rests disconformably on the Bertie waterlime (top of Salina of Siluric) having Eurypterus.

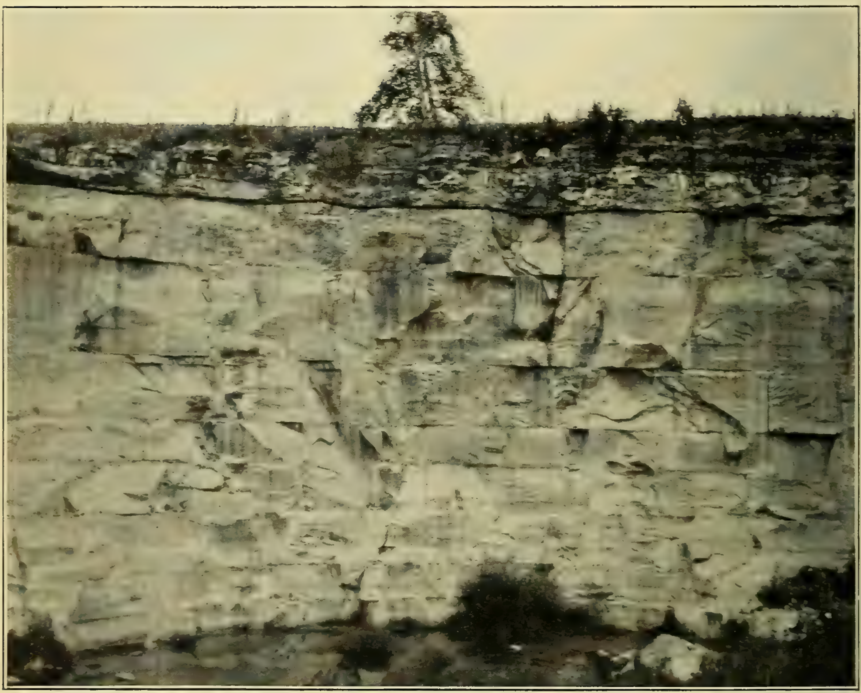


FIGURE 2.—BEAR GRASS QUARRIES, LOUISVILLE, KENTUCKY

The Onondaga coral reef rests disconformably on the Louisville coral reef

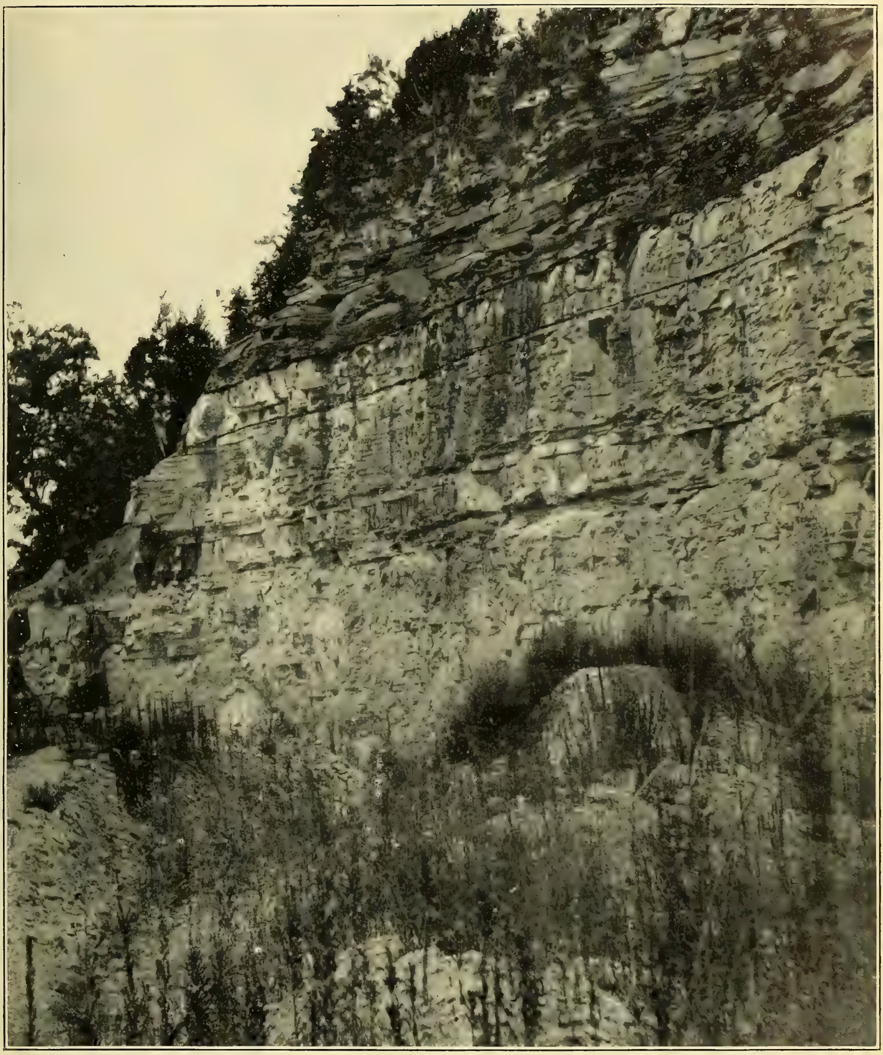
LIMESTONE QUARRIES NEAR BUFFALO, NEW YORK, AND LOUISVILLE, KENTUCKY blage is American in type, while the western has the widely distributed Euro-Asiatic aspect. What is it that keeps these faunas distinct, when at times the formations in which they occur approach one another in type to within a distance of 50 miles, or even less? At present there are no visible lands separating them, nor even easily discernible geologic structures indicating former land barriers. Those who have studied their relationships hold that a land barrier did exist—the Kankakee axis—which kept apart these distinct provincial faunas. Many similar cases are indicated on the maps here presented. It is known that the formations thin out in places and are petrologically different on the two sides of such barriers. As long as these physical conditions are maintained the faunas remain distinct, but when the deposits spread far and wide the faunas, through blending, lose their individuality.

For the benefit of those not believing in land barriers unless they can see decided unconformities against which two given seas deposited their similar or dissimilar sediments, a few photographs will be here introduced, showing conformable strata with wholly unrelated superposed faunas. In the Bennett quarries at Buffalo, New York (plate 46, figure 1), in a little cliff less than 20 feet high, may be seen the Middle Devonic Onondaga coral limestone reposing upon a slightly irregular surface of the Cobleskill-Siluric. Elsewhere, between these two deposits, the Manlius-Siluric and all the Lower Devonic were laid down. Such sections are by no means rare. In western Tennessee, at Newsom, is a quarry face about 75 feet high (plate 47), at the top of which occurs the widespread Ohio black shale, here representing the Lower Mississippic. With sharp petrologic change, but otherwise without apparent break, this stratum rests upon a zone about six feet thick, bearing the impress of Onondaga time, for in this horizon has been found the well known pentremite *Nucleocrinus verneuili*. Therefore here is absent all the Hamilton, which at Louisville is a limestone with a thickness of 28 feet, and in central New York is 500 feet in depth (shales). In the Tennessee region under discussion, below this thin limestone is another break, for the Onondaga rests on the Louisville-Siluric. Between these two beds, therefore, all the Salina, Manlius, and the entire Lower Devonic are missing. Fifty miles to the west, however, most of the Lower Devonic has appeared between these Siluric and Middle Devonic formations. The disconformity last mentioned is one of vast extent, and may again be well seen at Louisville, Kentucky (plate 46, figure 2), in the large quarries along Bear Grass creek, where the same relation exists as at Newsom, Tennessee; in both instances the Onondaga Middle Devonic coral reef reposes upon the Louisville-Siluric coral reef. This extensive land interval, which is represented in the photograph by a horizontal line, can be traced through these quarries for half a mile, yet the two deposits can not be readily separated by any other means than the entombed fossils. Such disconformities are numerous and are of general occurrence in the central portion of the United States and Canada, where they have led to the discovery of various land barriers so necessary to a proper interpretation of faunal provinces.

It has been assumed by some geologists that where such disconformities occur the sea has been continuous and has failed to deposit sediments, or has even scoured away parts of the sea-bed, as is the case with the present gulf current when it is forced between narrow passages like that between Florida and the Bahamas. The question may be asked of those making this assumption: Why is it that a sea which has not laid down strata for thousands or perhaps hundreds of thousands of years suddenly begins to deposit sediments? In this connection it should be noted that during Louisville time a clear sea was the agent for the precipitation of coral-reef limestone, and that very much later, in Onondaga time, it was followed by another sea with identical physical characters. During the interval, if the sea were present, it did not accumulate material nor remove an appreciable thickness of the limestone by leaching. On the other hand, scouring of the sea-bottom is known only where the Gulf stream flows swiftly, a condition which is exceptional in existing seas.

Neither can it be admitted that the land interval was less in time than the fossils indicate, nor that extensive sheets of limestone have suffered erosion. If the latter were true, outliers of these missing horizons would be found, for the land was so low that the wearing away could not have removed them completely over hundreds of miles of extent. Since late Ordovicic time the Cincinnati region has been above the sea, yet it has lost less than 300 feet by erosion, and probably the greater part of that has been taken away since the Pleistocene elevation. It is possible, however, that a thin Mississippic formation may have covered the Cincinnati area; but in any event less than 400 feet have been eroded since the close of the Ordovicic.

Currents as fauna distributors.—The statement has been made that it is not necessary to assume the presence of land barriers to have distinct faunas in a wide spread supposedly continuous sea, but that such will be kept separate and distinct by currents having decided differences in temperature. In other words, two definite faunas may exist side by side in the same marine waters, this condition being certainly in force at present in the Atlantic ocean off the coast of America. On the continental shelf, as far south as cape Hatteras, lives the fauna of the cooler waters due to



QUARRY FACE AT NEWSOM, TENNESSEE

Upper beds are the Ohio black shale (Lower Mississippic), resting disconformably on 6 feet of Onondaga limestone (Lower Middle Devonic), which in turn lies disconformably on the Louisville (Middle Siluric).

the Arctic currents that flow south along this region. Impinging against the outer edge of the continental shelf in the deeper water occurs the warm Gulf stream, and yet the two faunas are quite distinct to within about 10 miles of each other. All along the present shores, where there are currents of cold and warm water, it is the rule to find distinct faunas on each side of prominent land promontories. Furthermore, many of the cold-water species of the northern Atlantic follow the cold water south of cape Hatteras into the deeps beneath the Gulf stream.

While the truth of these statements is not to be denied, yet in dealing with existing life as the basis for interpreting geologic faunas one must not lose sight of the important fact that the marine waters of today are those of a glacial climate. During most of geologic time the temperature of the ocean was far more even than at present, with no such variations as now occur in the northern Atlantic from 72 degrees Fahrenheit at the surface to 33 degrees Fahrenheit or even less in the abyss. During the Ordovicic, Siluric, and Devonic there were only slight differences in temperature, and these variations were no doubt due to latitude. That during these times the marine waters had a nearly equable temperature is seen in the very similar Mohawkian faunas of Tennessee, New Jersey, Minnesota, and Baffin Land; reef corals of Devonic age occur in abundance not only in Kentucky and Indiana, but almost equally so in Alaska, while certain of the Siluric faunas of the interior region are undoubtedly derived from those of northern Europe, which migrated to America by way of north Greenland. Finally, attention may be directed to the fact that in Miocene times magnolias flourished in Greenland.

The region of the strait of Gibraltar is a good example of an almost complete land barrier that is ineffectual as a faunal barrier because of a small opening in it. The Mediterranean entrance into the Atlantic is only 9 miles in width, yet hundreds of warm, shallow-water species have spread north along the coasts of Spain, Portugal, France, and even to the south shore of England. Some of the species have distributed themselves along this shoreline fully 1,500 miles, measured in a straight line. On the other hand, the deep-sea faunas on each side of this submerged barrier at Gibraltar do not spread, owing to the great difference in temperature. From this it is seen that however small an opening may exist between two bodies of water with nearly the same temperature (Atlantic, 72 degrees; Mediterranean, 75 degrees), the two faunas will intermigrate in spite of the further fact in the present instance that the Atlantic is less saline and becomes progressively cooler toward England.

It can be said with certainty that in marine continuous waters, either warm or cold, but of fairly equable temperature throughout the year, the faunas become very widespread. As examples may be cited the Antillian shallow-water fauna living within 60 fathoms, which has spread to Pernambuco, Brazil, Florida, and Bermuda, and a few species even to cape Hatteras. The same is true in the Pacific ocean from north Peru to southern California, and these are distances representing 3,000 miles or more. In this wide distribution undoubtedly the currents have greatly facilitated migration and the blending of faunal elements, yet a far greater factor is an equable oceanic temperature throughout the year. Similar dispersion may be noted in the case of single species: for instance, that of *Purpura lapillus*.

> "This group is abundant in the North Atlantic, and has made its way through the Boreal region into the Pacific, being modified into several geographic races. On the western coast of North America, where there are no sudden changes in the temperature of the sea water, this group has made its way as far south as Margarita Bay, in latitude 24° N., mean temperature 23° C. On the Asiatic side it has made its way through Bering Sea down the shores of Kamschatka with the cold water, but has been stopped by the sudden change of temperature at Hakodadi, latitude 41° N., Japan, mean temperature 11° C., where the warm Japan current meets the cold current from Bering Sea. That this is not an accident of distribution is shown by the fact that the group of *Purpura lapillus* has, in the Atlantic, a similar distribution, and for the same reasons. On the African side it reaches latitude 32° N., mean temperature 19° C., and on the American side it is barred back by the sudden change of temperature at lat. 42° N., mean temperature 11° C. There can be no doubt that the temperature, or rather evenness of change of temperature, controls the distribution of *Purpura lapillus* now" (J. P. Smith, von Koenen, Festschrift, 1907: 415).

During periods of greatest inundation in warm climates, as those of the Mohawkian and the Niagaran of the Mississippian province and of the Middle Devonic of the Euro-Asiatic province, there are in America almost universal faunas. This is also in conformity with the postulate that during times of extensive inundation the land barriers are least effective. That the physical conditions of the Paleozoic can not be altogether determined by the character of the present Atlantic may be proved by the tabulations of shallow-water life presented by Doctor Dall. He states that in the existing "cool temperate zone," where the minimum winter temperature of the water is not below 40 degrees Fahrenheit, in both the North Atlantic and the Pacific ocean, and at any station where good collections have been made, there live on the average 407 shell-bearing molluscan species. In the "warm temperate zone," having a temperature of between 60 degrees and 70 degrees Fahrenheit, the average is 483 species, while in the tropical zone the average is 629 species. It is also stated that these figures compare favorably with the number of species representing Tertiary faunas, but that with the latter the tendency is toward even larger numbers, because the collecting of fossils is carried on under conditions far superior to those in force today when dredging for existing faunas.

On comparing these figures with those for the Cincinnati region, probably the best known Paleozoic locality in America, it will be found that from the Cincinnati series, which has a maximum thickness of about 850 feet, there have been gathered about 1,100 species, if the undescribed forms represented in the various collections are included. This series is now divided into 14 zones, each having an average thickness of about 60 feet, thus giving a fauna of about 80 species for each zone—a figure far below the average in the faunas of the present oceans, the smallest number being 407 species. The Richmond formation is the most fossiliferous, with an estimated number of 500 species; as there are 6 zones in this formation, this will give but 83 species to each subdivision, the latter having, according to Cumings, an average thickness of 60 feet. Further, in the Cincinnati faunas all the known fossils are included, not the molluscs alone. Along the Atlantic shore, from the Rio Grande to the Arctic region, Dall lists 1,364 species of shelled molluscs within the 100-fathom zone. This is a far larger representation, probably four times greater, than that of the entire fauna of the American Trenton which has equal latitudinal extent.

Other and similar evidence could be offered, but it will suffice to close this subject by adding that no paleontologist who has looked into the present dispersal of faunas understands how currents of similar temperature can keep shallow-water faunas from intermingling. It was the currents and the equable temperature of the ancient seas that facilitated the migration of the shallow-water life, and this is especially true of the larval and adult animals living near the surface of the sea. Land barriers and shallow-sea marshes, together with decided temperature and saline differences in the water, are the effective causes preventing the distribution of faunas. Temperature and saline barriers, however, are comparatively seldom effective in geologic time, but the land barriers are continually occasioning the localization of faunas, and by their breaking down permit the intermigration of the localized biota. The entire subject of sea-currents should not be used to explain faunal differences, but for the present should be laid aside. The first need is to establish paleogeography, a result which has as yet not been attained.

Conclusions.—In making the maps herewith presented the greatest stress has been laid upon the distribution of faunas, both as to time and space, as known to paleontologists. When synchronous faunas were found to be different and a lapse of connecting strata occurred, these facts were interpreted as meaning that a land barrier more or less complete kept the faunas apart. It is fully realized that in the course of time it may be shown that these maps err on the side of too much restriction of the continental seas. It was thought, however, that by the present method of representation more certain progress would be attained than by assuming universal continental synthetic seas, which some paleontologists believe have not led to a proper understanding of the periodic encroachment of the oceans on the land.

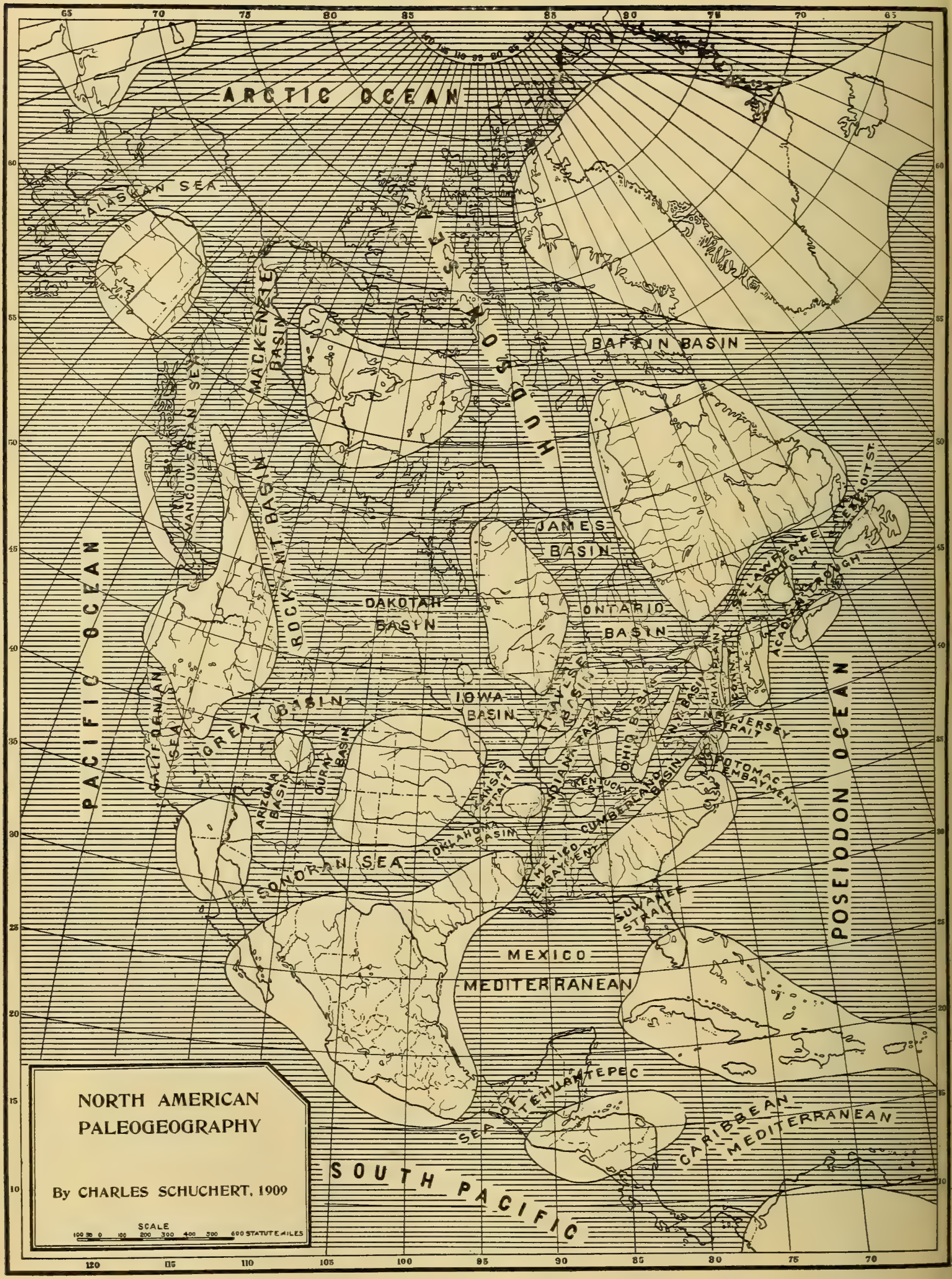
An analysis of fossil faunas indicates that from the earliest Paleozoic times there have been three permanent oceanic realms that have furnished life to the continental seas of North America. In the order of their importance these are: (1) The Gulf of Mexico mediterranean, (2) the Pacific, (3) the Arctic and the Atlantic. The faunas of the North Atlantic as a rule are restricted to Acadia and to the eastern portion of the Appalachian mountains, yet they frequently spread across these folds and mix with the life of the other regions. Those of the Pacific have a far wider range, and often occur as far east as Appalachia. The faunas from the Gulf or Mexican mediterranean are at times clearly tinged with an Atlantic facies, but oftener are more of the southern than of the northern European type, while at other times they are without doubt from the South American realm by way of the Pacific.

AREAL-GEOLOGIC METHOD

Having ascertained the nature of a fauna and its stratigraphic position, the next point of greatest value is the geographic distribution of the formation. Here geologic maps are of the highest importance, especially those that give lists of the local faunas. In this connection the Folios of the United States Geological Survey were most helpful, but all maps issued by the more prominent national and state surveys were scanned for information. The recently published International Geologic Map was likewise found to be very useful, particularly so for outlying regions of the North American continent.

PETROLOGIC METHOD

Marine conglomerates unmistakably indicate proximity to land, and are therefore of great value in paleogeography. Marine sandstones are also good indicators for shore conditions, shallow seas, and nearness to land, but are not so reliable as the conglomerates. In the interior region of the continental seas, however, sandstones are of rare occurrence. Mud deposits point rather to shallow seas, and black shales are thought to denote closed or stagnant arms of the sea, variably foul at the bottom, as in the Black sea of Russia. Such black shale deposits are the Utica, Genesee,


ARCTIC OCEAN
ALASKAN SEA
MACKENZIE BASIN
HUDSON SEA
BAFFIN BASIN
VANCOUVERIAN SEA
ROCKY MT. BASIN
JAMES BASIN
DAKOTAH BASIN
ONTARIO BASIN
ST. LAWRENCE TROUGH
ACADIAN TROUGH
PACIFIC OCEAN
CALIFORNIAN SEA
GREAT BASIN
ARIZONA BASIN
OURAY BASIN
IOWA BASIN
KANSAS STRAIT
OKLAHOMA BASIN
SONORAN SEA
MEXICO EMBAYMENT
INDIANA BASIN
OHIO BASIN
KENTUCKY ST.
CUMBERLAND BASIN
CHAMPLAIN
NEW JERSEY STRAIT
POTOMAC EMBAYMENT
POSEIODON OCEAN
SUWANEE STRAIT
MEXICO MEDITERRANEAN
SEA OF TEHUANTEPEC
CARIBBEAN MEDITERRANEAN
SOUTH PACIFIC
NORTH AMERICAN PALEOGEOGRAPHY
By CHARLES SCHUCHERT, 1909
SCALE
100 50 0 100 200 300 400 500 600 STATUTE MILES

CONTINENTAL SEAS OF PALEOZOIC TIME

Chattanooga, etcetera, the known faunas of which are of the nekton and plankton type. As a rule, limestones are indicative of seas of wider extent among low lands during times of moist and warmer temperature, while dolomites mark about the same conditions, but in shallower, evaporating seas. Oolites are formed in the littoral region of seas between tides where the lime salts accrete about a nucleus due to its repeated wetting and drying, and otherwise.

The interpretation thus given the various kinds of sediments has been applied in the construction of the present maps, but not with the same care as that given the faunas and the areal geology. Volcanoes and volcanic material have also been considered, but information regarding these has been plotted in only a few of the more striking times and areas of eruption. The positions of these are shown by asterisks.

DIASTROPHIC METHOD

Having ascertained the essential periods of emergence and transgression by the faunal method, the diastrophic principle was then used to fix the major time divisions. Taken by itself, the latter method is believed to be nearly as unreliable, where permanent results are concerned, as the petrologic method. In fact, the principle of diastrophism can rarely be used before taking the fossil evidence into account, for it is the latter that fixes and determines physical events. Diastrophism, however, is of much value in paleogeography, but it must follow, not precede, the evidence furnished by the fossils.

Continental Seas, or Negative Continental Elements

(See map, plate 48)

All the Paleozoic seas now engaging the attention of American stratigraphers are of the "continental" type—that is, their deposits have been furnished by shallow seas within "great continental basins." This fundamental generalization was first announced by Dana in 1856,[34] was repeated in 1863,[35] and was clearly defined in 1874.[36] The later term—"epicontinental seas"—of Chamberlin and Salisbury[37] has the identical meaning of continental seas.

The "Interior Continental region" is subdivided by Dana as follows: "(1) The Eastern interior east of the Cincinnati uplift; (2) the Central interior or Mississippi basin, and (3) the Western interior or that of the Eastern Rocky Mountain slope" (1890: 41). These broad divisions still hold good and with slight modification are adopted by the writer, the shorter names applied by later stratigraphers, chiefly by Walcott,[38] being employed. The "eastern interior sea" will be restricted to Dana's original definition—that is, to the great Appalachian syncline east of Alleghania and Tennesseia and west of Appalachia; for this area, *Appalachian sea* will be used instead of Dana's original name, "Appalachian region." "The central interior or Mississippi basin" of Dana includes the various local basins on either side of the Cincinnati axis, bounded on the east by Alleghania and on the west by Missouria, Llano, Siouxia, and Wisconsia. To this sea Walcott has given the name *"Mississippian sea,"* following Dana's earlier determination. "The western interior sea" Walcott has called *"Cordilleran sea,"* while "the eastern border basin or region" of Dana (1874: 146) is here changed to *Saint Lawrence sea.*

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[34] Dana: American Journal of Science, vol. 22, 1856, pp. 335-349.

[35] Dana: Manual of Geology, 1863.

[36] Dana: Ibidem, second ed., 1874, pp. 145-146. Also Bull. Geological Society of America, vol. 1, 1890, p. 41. Manual of Geology, fourth ed., 1895, p. 461.

[37] Chamberlin and Salisbury: Geology, vol. 1, 1904, p. 11.

These bodies of water and others to be named in the following pages are distinct faunal provinces whose successive biota are received from those great perpetual realms of marine life—the Pacific, Atlantic, and Arctic oceans. They are the "negative elements" of Willis,[39] yet as the oceanic areas are the true negative elements the writer has designated these seas as *negative continental elements.* They have been defined by Willis as follows: "By contrast with the positive elements of the continent which are recognized by absence of sediments and preponderance of unconformities, the negative elements are distinguished by the sediments which bury them."

According to the derivation of their faunas, these various elements or seas may be grouped as follows:

Seas with Atlantic or Poseidon life.—Primarily (1) Saint Lawrence, (2) Potomac embayment; secondarily (1) Appalachian, (2) Mississippian, and (3) Hudson. By inference, Suwanee strait.

Seas with Mexico-Caribbean life.—Primarily (1) Gulf of Mexico overlap, (2) Coloradoan, and (3) Mississippian; secondarily, Appalachian. By inference, Sea of Tehuantepec.

Seas with Pacific life.—Primarily (1) Cordilleran, (2) Sonoran, (3) Logan, (4) Californian, and (5) Vancouverian; secondarily, Alaskan. At times primarily, but as a rule with slight Pacific incursions, Mississippian.

Seas with Arctic life.—Primarily (1) Hudson, and (2) Alaskan; secondarily, (1) Cordilleran, (2) Coloradoan, and (3) Mississippian.

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[38] Walcott: Proc. American Association for the Advancement of Science, vol. 42, 1894, pp. 129-169.

[39] Willis: Bull. Geological Society of America, vol. 18, 1907, p. 398.

The foregoing arrangement of these seas will probably impress the reader in two ways: First, the great number of North American seas, and, second, their rather free intercommunication. The multiplicity of seas, which in the main were of Paleozoic time, unmistakably indicates shallow bodies of water variously separated by more or less ineffective land barriers. A survey of the paleogeographic maps presented in this paper will make this fact abundantly evident, and it may be likewise observed that not only did the marine waters flow in on the land from the four sides of the North American continent, but that the seas were localized among lands that suggest an archipelago of large islands. Further study will show that the Paleozoic continental seas began in a small way, pulsated back and forth over the continent, and, if a few irregularities are disregarded, increased in area until they almost completely submerged North America in Middle Ordovicic time. This great inundation was dominated by the Pacific. The oscillatory nature of the seas continued, yet during the Siluric the Arctic waters were the dominating force. With each recurring climax of submergence, however, it is seen that the pulsations became smaller and smaller until the close of the Paleozoic, when North America was again as large as it had been at the beginning of this era. For a long period the entire continent then remained positive except along the border region of the Pacific, which ocean during the Triassic overlapped great areas and in the late Jurassic developed the Logan sea. During this period, however, contraction and subsidence of this immense ocean had gone on, and thrusting now took effect, giving birth to the Sierra Nevadas. About this time subsidence also took place over much of eastern Mexico, being probably caused by the thrusting of the Pacific ocean indicated in the appearance of the Sierra Nevadas. This thrusting was continued for a period equal in length to the Comanchic, and resulted in the greater extension of the Gulf of Mexico not only over the larger part of Mexico, but the syncline stretched into the United States as far north as Kansas. A marked but short withdrawal of this sea then took place, when the same syncline was further extended, giving rise to the Coloradoan sea connecting the Gulf of Mexico with the Arctic ocean. That this trough continued to subside is shown by the fact that in Montana it contains about 12,000 feet of marine deposits of Colorado and Montana age, and these series are said to be followed by a similar thickness of Laramie and Livingston beds. In the development of this trough must be assumed the gradual rise of the Rocky mountains in the West, a considerable portion of whose elevation has gone toward filling the syncline.

Along the northern Atlantic thrusting culminated with the early Permic revolution, since which time this ocean has gradually eaten its way westward, assisted by block faulting seaward either in late Jurassic or early Comanchic. This action continued until late in Cretacic times, when the ocean overlapped the continental shelf all along the coast from New Jersey southward, thus connecting with the Gulf of Mexico overlap.

The various seas are defined as follows, being arranged in alphabetical order:

Acadian trough.—See Saint Lawrence sea.

Alaskan sea.—The Paleozoic and Mesozoic seaways about Yukonia. Usually these waters were but the overlapping continental extensions of the Arctic and North Pacific oceans, but at times the individual parts were united and then submerged most of Alaska. This sea was also at times in connection with Mackenzie basin.

Appalachian sea.—In one way or another this continental sea has been recorded in geological literature since the work of W. B. and H. D. Rogers in 1840. Williams[40] appears to have been the first to give it the name "Appalachian basin," while Walcott called it "Appalachian sea."[41] It comprises the Appalachian region of Dana[42] and his "eastern interior east of the Cincinnati uplift."[43] Other names applied to the same sea are: "Appalachian gulf" or "strait,"[44] "Appalachian Valley trough" with reference to the eastern part with Cambric-Ordovicic formations,[45] Cumberland basin for the post-Ordovicic formations to the west of the "Appalachian Valley fold or barrier,"[46] and "Cumberland channel,"[47] which embraces the southern area between the Cincinnati axis and Appalachia.

Appalachian sea refers to the continuously subsiding, narrow, Paleozoic syncline, "or group of troughs,"[48] to the west of Appalachia, extending from Alabama into eastern New York. In Pennsylvania this trough contains approximately 30,000 feet of deposits. The Appalachian sea was not distinctly separated from the Mississippian sea until the rise of the Cincinnati axis, previous to which time the dominating Pacific waters lapped Appalachia. Subsequently this sea received its faunas in the main from (1) the Mexico-Caribbean mediterranean, (2) the Atlantic or rather Poseidon ocean, and (3) the Mississippian sea. When these were from the first named source entrance was effected by way of the Mexico embayment. During the late Cambric and the Ordovicic Atlantic faunas migrated into this sea from the Saint Lawrence sea by way of the Champlain trough, and during the early Devonic through the Connecticut trough. During much of Paleozoic time, however, the faunas came directly from the Atlantic through *New Jersey strait.* This connection with the Mississippian sea was either a wide one through the Ohio basin or was much restricted by the more or less neutral land Alleghania. In general, it may be said that the faunas of the Appalachian sea were in harmony with those of the Mississippian sea because of their open communication one with another. At times, however, these seas were completely isolated, in which case the Appalachian sea, particularly its northern end, took on a decided Atlantic faunal aspect, and it should be stated that the Appalachian sea always showed more of this character than did the Mississippian sea.

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[40] Williams: Bull. Geological Society of America, vol. 1, 1890, p. 481.

[41] Walcott: Proc. American Association for the Advancement of Science, vol. 42, 1894, map and pp. 141-145.

[42] Dana: Manual of Geology, 1874, p. 146.

[43] Dana: Bull. Geological Society of America, vol. 1, 1890, p. 41.

[44] Willis: Maryland Geological Survey, vol. 4, 1902, pp. 40, 52.

[45] Ulrich and Schuchert: Rep. New York State Paleontologist, 1902, p. 638, and map.

[46] Ibidem, pp. 638, 647, 649.

[47] Williams: American Journal of Science, vol. 3, 1897, p. 398.

[48] Dana: Bull. Geological Society of America, vol. 1, 1890, p. 42.

During the late Cambric and the greater part of the first half of the Ordovicic the Appalachian sea deposits were in the main of a calcareous dolomitic nature; yet subsequently, when the trough was clearly defined, its sediments were chiefly muds and sands. This was especially true of the northern portion of the trough, and attained its climax in Devonic times, when 10,000 feet of Middle and Upper Devonic strata were laid down.[49] The present writer believes that the major amount of this material came from Acadia, or more specifically from Taconia, and that the cause of this great thickness was the narrowness of the Appalachian trough, hemmed in on the west by Alleghania. The first restriction of this trough came with the Cincinnati uplift, which was due to the Taconic revolution that began in early Utica time and culminated with the Richmond. The rise of the more or less neutral land Alleghania was also contemporaneous with this uplift. Ulrich thinks that the first restriction appeared as early as the Lower Mohawkian. He states that these deposits nearly all overlapped to extinction on its flanks.

The Appalachian sea was at times divided into two parts by a land area in southern Virginia, when either the northern or the southern portion, or both, may have been occupied by independent marine waters. To the northern Appalachian sea, extending from New York (west of Taconia) to Virginia (west of Appalachia), the name *New York basin* is here applied, as the history of this area is best known in the State of New York. The region about Albany, New York, has been called by Dana[50] the "Northeast bay." The southern Appalachian sea may take the name *Cumberland basin*; it extended nearly from Tennessee to Alabama, where it merged into the Mexico embayment. The Paleozoic deposits of this basin are not so thick as those of the northern area.

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[49] Willis: Bull. Geological Society of America, vol. 18, 1907, p. 399.
[50] Dana: Bull. Geological Society of America, vol. 1, 1890, pp. 42-43.

In the Ordovicic the eastern part of the Cumberland basin was occupied by two distinct faunal elements, the western one of which contained the life of the Mississippian sea, while the other derived Atlantic (Poseidon) faunas through the Mexico embayment. The most easterly portion of the Cumberland basin area has been named *Lenoir basin.*[51] This basin was again medially divided by "several disconnected longitudinal folds high enough to affect the direction of currents, and consequently the character of the sediments, and in a smaller degree faunal distribution. In a general way the deposits may be divided into an eastern, *Athens trough,* and a western series, *Knoxville trough*" (Ulrich and Schuchert, 1902, page 644).

Arctic ocean.—Of all the permanent basins this ocean has had the least effect, physically and faunally, on the North American continent. During the Siluric, however, its waters attained a broad entrance into the United States through the medial regions of the continent. In Middle and Upper Devonic times its inundations were considerable, though less than half those of the previous period, while in the Mississippic they were far less effective. But once, subsequently, during the Cretacic, did this ocean have free access to the continent through the Coloradoan sea.

Arizona basin.—See Sonoran sea.

Athens trough.—See Appalachian sea.

Atlantic ocean.—Throughout the Paleozoic, and during most of the Mesozoic, there was no Atlantic ocean in the sense of today. During the vast time indicated above the North and South Atlantic were independent bodies of water separated by Gondwana, uniting Africa and South America. For this reason it is not proper to speak of the Atlantic until after late Mesozoic time, when the southern Atlantic, or *Nereus,* and the northern Atlantic, or *Poseidon,* were more or less widely united. For further remarks, see Poseidon ocean.

Baffin basin.—See Hudson sea.

Californian sea.—A continental border sea of the Pacific across California during the Paleozoic and Mesozoic. In the Triassic this sea extended to Nevada, Idaho, Oregon, and Washington. Like most continental border regions, the Californian sea was considerably affected by volcanic deposits. These are known in Devonic, Pennsylvanic, and early Mesozoic time. For the present this term has a very indefinite meaning. Walcott[52] applied "Californian sea" to the area of Paleozoic deposits in California and "of western British Columbia." In the present work the latter area is referred to the *Vancouverian sea.*

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[51] Ulrich and Schuchert: Rep. New York State Paleontologist, 1902, pp. 634, 644, and map.

[52] Walcott: Proc. American Association for the Advancement of Science, vol. 42, 1894, pp. 129, 145, with map.

Caribbean mediterranean.—See Mexico-Caribbean mediterranean.

Champlain trough.—See Saint Lawrence sea.

Chazy channel.—See Saint Lawrence sea.

Coloradoan sea.—The western great inland continental sea of Cretacic time extending from the Gulf of Mexico to the Arctic ocean. Its individual parts were the Mackenzie and Rocky Mountain basins, defined under Cordilleran sea. The eastern Great Plains area, from Manitoba to Oklahoma, may be called the *Great Plains basin.*

Connecticut trough.—See Saint Lawrence sea.

Cordilleran sea.—This great Paleozoic continental sea of the Rocky Mountain region has been known a very long time. Its syncline was due to thrusting of the Pacific mass, and its faunas were usually dominated by those of this ocean. It probably came into existence long before the Cambric. Dana[53] has called it the "Western Interior or that of the Eastern Rocky Mountain slope." The name as used by the writer was given by Walcott.[54] Willis[55] designates it the "Rocky Mountain trough," and Williams[56] has included the northern end of this sea in his "Dakota channel," a name that will be used in connection with the Cordilleran sea.

During its time of maximum inundation the Cordilleran sea extended from the Arctic ocean to the east of Yukonia and Cascadia, and united with the Pacific ocean by way of the Great Basin and southern California. At times it was also connected southward with the Sonoran sea. Its faunas were derived chiefly from the Pacific and less persistently from the Arctic ocean, and these elements combined, or the former alone, may have spread during the earliest Paleozoic as far eastward as Appalachia and Taconia. After Siluric times the Cordilleran sea was never in wide open communication with the Mississippian sea, but these two great continental basins had as a rule their own distinct faunas, derived either from the Pacific or the Atlantic (including the Gulf).

The Cordilleran sea had several distinctive parts that must be named and defined for easy reference. The most persistent portion was the *Great Basin* area, well known since the work of King (1878. See also Dana, 1890, page 46), which embraced eastern Nevada, northwestern Utah, western Wyoming, southeastern Idaho, and the Inyo region of California.

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[53] Dana: Bull. Geological Society of America, vol. 1, 1890, p. 41.

[54] Walcott: Proc. American Association for the Advancement of Science, vol. 42, 1894, pp. 143, 144, with map.

[55] Willis: Bull. Geological Society of America, vol. 18, 1907, p. 399.

[56] Williams: American Journal of Science, vol. 3, 1897, p. 394.

According to King, there were 32,000 feet of Paleozoic sediments in this great syncline. As the faunas of this basin were decidedly Pacific in origin, it must have had free communication with the dominant ocean, seemingly through central California. Southward the Great Basin was often in connection with the Sonoran sea by way of the Arizona basin. To the north this area passed into the *Rocky Mountain basin* of Wyoming and Montana (Dana, 1890, page 46), and it frequently extended far into the north across Alberta, eastern British Columbia, and western Athabasca (northern Rocky Mountain trough of Willis, 1907, page 399), then uniting with the Pacific ocean by way of the *Mackenzie basin.* The latter extended along the valley of the Mackenzie river between Yukonia and Mackenzia.

In the region of the Rocky Mountain basin the Cordilleran sea often overlapped southeastward across the Dakota states, and connected with the Mississippian sea through the *Iowa basin.* This was the *Dakota basin,* first designated by Williams as the "Dakota channel" (1897, page 394). The original definition made this term applicable to Devonic waters having Pacific-Arctic assemblages of life and in restricted communication with the Mississippian sea. The name, however, is of more general application for Paleozoic seas repeatedly covering the same common area. During Middle and late Ordovicic the Dakota basin was in wide open communication with the Mississippian sea, at which time there was a general commingling of northern Cordilleran and Hudson Sea faunas with those of the Mississippian. During the Siluric the Dakota basin connected for the last time with the Hudson sea north of the Dakota states, while in the Devonic it stretched far across these states; in the Mississippic and Pennsylvanic appearing to be less wide and extending farther south across South Dakota and northern Nebraska.

Dakota basin.—See Cordilleran sea.

Exploits channel or trough.—See Saint Lawrence sea.

Fundy basin.—See Saint Lawrence sea.

Gaspé-Worcester trough of Dana[57] had no individual development as a seaway, as far as the writer can learn. Its northern end was a part of the Saint Lawrence trough, while the southern portion represented an indefinite depression more apparent in the present structure than in the Paleozoic seas. It is defined as follows: The trough was situated between the New Hampshire range and the Mount Desert range. It extended "from Gaspé, on the bay of Saint Lawrence, over much of northern New Brunswick and central Maine, and continued to Worcester, Massachusetts."

Great Basin.—See Cordilleran sea.

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[57] Dana: American Journal of Science, vol. 39, 1890, p. 380.

Great Plains basin.—See Coloradoan sea.

Hudson sea.—A very shallow continental V-shaped sea of enormous extent during Ordovicic and Siluric times, having wide open connection with the Arctic ocean across Franklin archipelago, and by way of the Dakota basin through the Cordilleran sea. During the Ordovicic there was also free communication with the Atlantic by way of Baffin basin. In southern Baffin Land are Middle Ordovicic faunas of the same aspect as those of Akpatok island, in Ungava bay. Because these localities are so near the present deep seaways of Hudson strait and Davis strait, it seems reasonable to assume this Atlantic (Poseidon) communication. To the south this wide sea narrowed between Ungava and Keewatinia; the northern portion of this area may be known as *James basin* and the southern part as *Ontario basin.* During the Middle and Upper Ordovicic these basins communicated uninterruptedly with the Mississippian sea, but far less openly with the Saint Lawrence sea. In the Siluric the southern communications were continued, but the eastern opening was of short duration. In the Middle Devonic the Mississippian sea occupied the Ontario and James basins for the last time.

Indiana basin.—See Mississippian sea.

Iowa basin.—See Mississippian sea; also Cordilleran sea.

James basin.—See Hudson sea.

Kansas strait.—See Mississippian sea.

Kentucky strait.—See Mississippian sea.

Knoxville trough.—See Appalachian sea.

Lenoir basin.—See Appalachian sea.

Levis channel.—See Saint Lawrence sea.

Logan sea.—An extensive, late Jurassic, western continental sea of very short duration, with northern Pacific connections. It extended from northern British Columbia across northern Cascadia, thence southward throughout the Rocky Mountain area into northern Arizona, and eastward into western South Dakota. This sea was correctly mapped by W. N. Logan,[58] for whom it is named.

Mackenzie basin.—See Cordilleran sea.

Mediterranean refers to those deep extensive bodies of marine waters situated between continents, with usually but one opening into an ocean. These were also permanent seas, true negative elements, whose boundaries, however, are changing more constantly than those of the oceans. The Gulf of Mexico-Caribbean sea has been named by Krümmel "the American mediterranean." See Poseidon ocean.

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[58] Logan: Journal of Geology, Chicago, vol. 8, 1900, p. 245.

Mexico-Caribbean mediterraneans.—These mediterraneans appear to be of very ancient origin; the former certainly existed previous to the Cambric. There is today free communication between them by way of the Yucatan channel, which may not have been the case throughout the Paleozoic. The Caribbean may have occurred as a deep-sea extension of the Pacific, land locked in the east, and stretching across Costa Rica and Panama during the Paleozoic and Mesozoic, with overlaps across northern Archiguiana. Its Atlantic, or Poseidon, connections across Antillia (lesser Antilles) were established either late in Mesozoic or early in Cenozoic times.

Throughout most of the Paleozoic the Mexico mediterranean was in open communication with the Mississippian sea by way of the *Mexico embayment.* The Mexican gulf "once stretched to the Arctic sea," and was "in early time but the deeper part of the continental ocean" (Dana, 1856, 345). It connected with the Pacific by way of the Sea of Tehuantepec certainly in the Siluric and Pennsylvanic, and probably also in the Devonic. During Mesozoic times Mexico and the Gulf states were widely inundated by the gulf, although this submergence was less in the Tertiary. The Paleozoic faunas of the Gulf of Mexico greatly affected the life of the Mississippian sea, with its decided South American connections which spread north along the western side of Archiguiana. The faunas in the Mesozoic, however, were Atlantic and agree best with those of southern Europe, though additions at times appear from western South America.

Antillia seems to have been submerged for the first time by the Mexico-Caribbean mediterranean late in the Mesozoic, and thus remained during the Eocene and Oligocene, when this region is represented by one vast ocean with a few small islands.

Mexico embayment.—See Mississippian sea.

Mississippian sea.—This vast Paleozoic continental sea was first defined by Dana[59] as "the Central interior or Mississippi basin," but later was changed by Walcott[60] to "Mississippian sea."

This shallow Paleozoic sea variously occupied more or less of the Mississippi and Ohio drainage areas, and was usually in free communication with the Appalachian sea. During Ordovicic and Siluric times it was also in open connection with the Hudson and Cordilleran seas, but after the Siluric only occasionally with the latter area. The chief and most persistent source of its waters and faunas was the Mexico mediterranean, and secondarily the Atlantic (= Poseidon) by way of the Appalachian sea.

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[59] Dana: Bull. Geological Society of America, vol. 1, 1890, p. 41.

[60] Walcott: Proc. American Association for the Advancement of Science, 1894, p. 144, with map. Also see Ulrich and Schuchert, Rep. New York State Paleontologist, 1902, pp. 636, 660.

Only during Middle and Upper Ordovicic times was there connection with the Saint Lawrence sea north of Adirondackia. Subsequent to the Ordovicic the main topographic features of the Mississippian sea were the islands of the Cincinnati uplift and the other islands or peninsulas Missouria, Wisconsia, Kankakeia, and Alleghania. These were low lands more or less subjected to marine inundations. Cincinnatia, Missouria, and Wisconsia were the most persistent, and all of these lands had their origin in movements previous to the Middle Mohawkian of the Ordovicic.

Outside of the Oklahoma basin the deposits of the Mississippian sea are far less in thickness than those of the northern Appalachian trough or the Great Basin of the Cordilleran sea. In the main they consist of calcareous shales and limestone often inclosing a profusion of fossils. The strata are often warped and rarely folded (exception, the Wabash axis), but in places there is considerable faulting.

The constantly changing topographic features of the Mississippian sea cause its deposits and faunas to be much localized and variable. These conditions make the work of the biologist all the more interesting, because difficult.[61] To facilitate the description of these localized sediments and faunas it is necessary to name the various basins bounded by the featureless lands. The Mexico mediterranean effected a wide entrance through the *Mexico embayment* between Llano and Appalachia, an area now deeply buried beneath post-Paleozoic deposits. Northeasterly this embayment may have continued into the *Indiana basin*[62] to the west of the Cincinnati uplift and east of Missouria and Kankakeia, or into the Appalachian sea by way of the Cumberland basin. The latter may also have extended into the *Ohio basin* of Ohio and western New York on the eastern side of the Cincinnati uplift and west of Alleghania (a restricted usage of Ohioan province[63]), or the Ohio basin may have been in communication with the Indiana basin around the north end of Cincinnatia. During the Ordovicic and Siluric the Ohio and Indiana basins again may have had open communication with the Ontario and James basins and the Hudson sea. In Devonic times this northern extension did not pass beyond the James basin, and in late Devonic the northern boundary of the Mississippian sea was restricted to the Ohio and Indiana basins. At different times the latter basins were connected by *Kentucky strait,* which passed across the Cincinnati uplift in Kentucky.

During the Devonic *Traverse basin* (Schuchert, 1903, 150) became the thoroughfare for the passage of the Cordilleran faunas of the *Iowa*

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[61] Also see Dana regarding this. Bull. Geological Society of America, vol. 1, 1890, pp. 43, 44.

[62] Schuchert: American Geologist, 1903, p. 148.

[63] Ulrich: Professional Paper, no. 24, of the U. S. Geological Survey, 1904, p. 91.

basin into the Mississippian sea. This basin was situated between Kankakeia and Wisconsia, and the waters passed around the northern end of the former land or across it. At other times Traverse basin was part of the Mississippian sea.

In the Devonic and early Mississippic, *Iowa basin* was part of the Cordilleran sea, but during the Cambric and Ordovicic it comprised the northwestern waters of the Mississippian sea in the states of Iowa, Minnesota, and Wisconsin. In the Siluric it embraced Iowa, Illinois, and Wisconsin, while during Pennsylvanic time it included the region immediately about Iowa.

Returning to the Mexico embayment, it is seen that its waters may have extended in a westerly direction around Llano into the *Oklahoma basin* to the south and southwest of Missouria and east of Siouxia. This syncline was a very persistent one, and according to Taff has a mass of Paleozoic sediments varying in thickness from 18,000 to 23,000 feet. During the Ordovicic this basin was in open communication with the Sonoran sea, but later was restricted to Mississippian waters and faunas. In Mississippic and Pennsylvanic times the Oklahoma basin passed north across western Missouria into the Iowa basin; this passage may be known as *Kansas strait.*

New Jersey strait.—See Appalachian sea.

New York basin.—See Appalachian sea.

Ocean, according to the Century Dictionary, applies to the great outward sea, the Atlantic, as distinguished from the inward sea, the Mediterranean. The word refers to the independent, vast, and permanent deep seas as the North Atlantic and Pacific negative elements.

Ohio basin.—See Mississippian sea.

Oklahoma basin.—See Mississippian sea.

Ontario basin.—See Hudson sea.

Ottawa bay.—See Saint Lawrence sea.

Ouray basin.—See Sonoran sea.

Pacific ocean.—During the Cambric and Ordovicic this vast and most ancient body of marine water mightily affected the North American continent, and spread its faunas not only along the shores of Appalachia, but in the early Ordovicic extended them into the Saint Lawrence sea as far as northwestern Newfoundland. Beginning with the Cambric, it connected with the Arctic sea to the east of Cascadia, but this union was in general not that of a wide sea. In Middle, and again in late Upper, Ordovicic time, however, there was a widespread inundation of the continent. At these times the faunas appear to have been dominated by that of the Pacific ocean. Later the life of the continental seas was not decidedly affected by the northern part of this ocean until the late Devonic and early Mississippic, while during the late Pennsylvanic its faunas did not extend beyond Colorado and New Mexico. Barring the invasion of the Logan sea, it was ever afterward restricted more and more to the edge of the North American continent. In other words, the western side of the entire continent was progressively enlarged and pushed up higher and higher, thus restricting this ocean to its ever deepening basin.

Poseidon ocean.—Throughout the Paleozoic the northern Atlantic waters were separated from the southern Atlantic by the great continent Gondwana, uniting Africa and South America across the medial region of the present Atlantic. It is, therefore, not correct to speak of the northern Atlantic until the present form of this ocean has been attained, which seemingly had its inception late in the Mesozoic. Von Ihering[64] has named the southern Atlantic waters south of Gondwana *Nereus* (he writes it Nereis), evidently after the father of the 50 Nereids. The northern Atlantic he regards as a part of Suess' Tethys (he writes it Thetis, one of the daughters of Nereus, but Suess distinctly refers to the consort of Oceanus, Tethys), the ancient Mediterranean that extended from the Atlantic to the Pacific and of which the present Mediterranean is the remainder. Since Tethys has its own and very distinct geologic history, and seemingly always had restricted communication with the northern Atlantic, it will be best to use this term in the sense given it by Suess.[65] As the northern Atlantic has an independent evolution from the southern Atlantic, it is here proposed to call the former the *Poseidon ocean,* after "the lord of the sea," known to the Romans as Neptune.

> "His home is a cavern in the depths of the sea, and not only does he know all the secrets of his element, but, like the sea-gods of the Babylonians and Germans, he possesses in general immeasurable wisdom. But he who would question him must first overpower him in a wrestle, and force him, despite his power of assuming like water itself a variety of shapes, to communicate to him his knowledge" (Steuding).

Repeatedly during the Paleozoic the waters of the Poseidon ocean entered the continental seas and there dispersed their faunas. At no time, however, did this life dominate these seas as did that derived from the Pacific realm during the early Paleozoic, and later that of the Mexico mediterranean. Subsequent to the earliest Mississippic the North Atlantic was excluded by land barriers, and in the Saint Lawrence sea after late Pennsylvanic time it did not again leave a record of its life. Near the close of the Mesozoic, and subsequently, it was an overlapping marginal sea.

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[64] Von Ihering: Archhelenis und Archinotis, 1907, p. 310, and map.

[65] Suess: Antlitz der Erde, III, pt. 1, 1901, p. 25. Natural Science, vol. 2, 1893, p. 183.

Potomac embayment.—An embayment of the Atlantic ocean across the Piedmont plateau, the "roofing slate area" of Virginia and Maryland. There is no evidence that this bay spread south of Buckingham county, Virginia, but it probably extended northeast across Delaware and New Jersey, uniting with New Jersey strait.

Relict seas.—These are brackish and finally fresh-water lakes, often of very large size, which have been connected with the ocean, but are now completely encircled by land. Examples are Caspian, Baikal, Tanganyika, etcetera, lakes, which still contain modified relicts of a former ocean. In America there is as yet no evidence of fossil relict seas, for all the previous continental seas appear to have been too shallow to permit of their origin during periods of continental emergence (see Walther: Einleitung in die Geologie, 1893, 130-134).

Rocky Mountain basin.—See Cordilleran sea.

Saint Lawrence sea.—The work of the Canadians made this sea known to American geologists years ago, but Dana[66] appears to have been the first to define its limits. It is his "Eastern Border basin or region," east and northeast of the Green Mountain range, and including New England, eastern Canada, New Brunswick, western Nova Scotia, the Gulf of Saint Lawrence, and Newfoundland.

This sea, trending northeasterly, was distinctly an interior sea, and owed its origin and position to the thrusting of the North Atlantic mass against the Laurentian shield. Dana[67] writes: "Even the far east Paleozoic area, including much of Nova Scotia and eastern New Brunswick, had its outside Archean boundary, and was a trough of Archean confines, not the margin of the open sea."

The portion of this sea best known is the area of the Saint Lawrence river and gulf to which has been applied the name *Saint Lawrence trough*[68] (see also Gaspé-Worcester trough). This trough, which was generally narrow, was in open communication with the northern Poseidon ocean and often transmitted its faunas freely to the Appalachian sea. As a rule, its life was that of the North Atlantic, being in harmony with the biotas of northern Europe. During the Ordovicic, however, there was a complexity of elements that are clearly of two widely different origins. Along the northern side of the embayment are found faunas that are positively of Mississippian derivation and that now occur scattered all the way from Adirondackia to Newfoundland. Closely adjacent to, or even thrust over on, these faunas are found others, usually graptolites, that are manifestly of the same province as those of northern Europe. These faunas are strikingly different, and as the entire Acadian region is one of extreme crushing and overthrusting, Ulrich and Schuchert[69] have assumed the existence of a land barrier to keep these two faunal provinces distinct. This fold or land barrier between the two seaways came into being at the close of the Cambric, and has been called the "Quebec barrier." To the northwest of this barrier was their *Chazy channel,* while on the opposite side of the same fold was their *Levis channel.* The definite Atlantic faunas of the latter may be traced southwesterly as far as New Jersey. These two troughs appear to have remained distinct until about Utica (?) time, when the Chazy basin ceased, owing to the folding and elevation in force during the Taconic revolution.

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[66] Dana: Manual of Geology, 1874, p. 146.

[67] Dana: Bull. Geological Society of America, vol. 1, 1890, p. 48.

[68] Dana: Ibidem, 1890, pp. 38, 379. Manual of Geology, 1895, p. 536.

In late Chazy time the Saint Lawrence sea had a distinct bay-like prolongation extending along the Ottawa valley north of Adirondackia; this has been named "Ottawa bay" (Ulrich and Schuchert, 1902, 639). During the later Ordovicic this depression was invaded either by the Mississippian or the Saint Lawrence sea; subsequently it appears to have been land, yet may again have been beneath the sea in Siluric time.

The connection of the Saint Lawrence sea with the Mississippian sea was of very short duration, and occurred north of Adirondackia during the Middle and Upper Ordovicic. During the late Cambric and much of the Ordovicic, however, there was much communication with the Appalachian sea through the *Champlain trough* (Dana, 1896, 461), but this passage was closed by the Taconic revolution of late Ordovicic time (see Dana, 1890, 43). In the early Ordovicic this channel was narrow and directly continuous with the Chazy channel, but subsequently it appears to have been considerably wider, embracing the Levis channel, its deposits occurring east as far as lake Memphremagog. During the Siluric there was no direct communication between the two seas, but beginning with the New Scotland interchange of faunas was again resumed, but now by way of the *Connecticut trough,*[70] which extended across the Taconic mountains into the New York basin of the Appalachian sea. The interchange of faunas was then continued well into the Onondaga, after which time Acadia was repeatedly compressed and elevated, thus forcing these two seas ever farther apart. The Connecticut trough was bounded on the west by the Green Mountain axis and on the east by the New Hampshire range. It contains, according to Dana, "Lower Silurian, Upper Silurian, and Devonian beds in the state of metamorphic schists . . . and crystalline limestones, but nevertheless affording fossils of each of the eras for their identification; and containing also the Connecticut Valley sandstone."

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[69] Ulrich and Schuchert: Rep. New York State Paleontologist, 1902, pp. 630-639.

[70] Dana: Bull. Geological Society of America, vol. 1, 1890, p. 38. American Journal of Science, vol. 39, 1890, p. 380. Manual of Geology, 1895, p. 461. Schuchert: American Geologist, 1903, p. 151. Clarke: Memoir no. 9, New York State Museum, pt. 1, 1908; pt. 2, 1909.

The "*Acadian trough*" of Dana[71] begins

> "in northern Newfoundland west of the northern part of Long range, and extending to St. George bay and Cape Ray, in southwestern [Newfoundland]; passing thence over the region of the Magdalen Islands, in the bay of St. Lawrence to Nova Scotia and New Brunswick on either side of the bay of Fundy; and thence to the region of Boston and Massachusetts Bay, and to that of Narragansett Bay in Rhode Island; and including rocks from the Cambrian to the Jura-Trias as identified by fossils."

The northern end of this trough to the Bay of Fundy region is well established, but the southwestern portion in Massachusetts and Rhode Island is based on Cambric and Pennsylvanic deposits. The former may be correctly placed in this depression, but the latter are fresh-water deposits that have the strike of the New Hampshire range. To the writer, therefore, they appear to form a local structural basin having no relations with the Acadian trough. The latter also includes the "*Fundy basin*" of Dana (1890, 37), an area which was receiving marine deposits as late as the Oriskanian.

The Saint Lawrence sea continued across northern and medial Newfoundland, along the basin of Exploits river, and thus was in direct connection with the North Atlantic. This is the "*Exploits trough*" of Dana.[72] This trough extended "along Exploits river across Newfoundland, southwestward, to La Poile bay and White Bear river, the length 200 miles." The main or southern mass of Newfoundland appears to have been land since Proterozoic times, and was smallest during the Lower Cambric, when it was overlapped not only in the north, but also in the south. Subsequent to the Cambric the southern portion of Newfoundland has been land continuously, while most of the northern or peninsular region was attached to Ungava after Ordovicic time. Exploits channel continued at intervals beneath the sea until about the middle of the Mississippic, when it was added permanently to the land.

Sonoran sea.—This was a fairly persistent Paleozoic continental sea extending across northern Sonora, southern Arizona and New Mexico, and medial Texas. As its faunas were those of the Pacific realm, it must have had connection with that ocean across Baja California. The Sonoran sea was often in communication with the Cordilleran sea by way of the *Arizona basin,* situated between the lands Ensenada and Utah. In the Upper Devonic especially, but also in the Mississippic and Pennsylvanic, this sea had a northern extension across western New Mexico and eastern Arizona and reaching into western Colorado; this may be known as the *Ouray basin.* The Devonic faunas of this basin were different from those of the Cordilleran sea.

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[71] Dana: American Journal of Science, vol. 39, 1890, p. 380.

[72] Dana: American Journal of Science, vol. 39, 1890, p. 381. Manual of Geology, 1895, p. 461.

At certain times during the Cambric and the Ordovicic, the times of wide Pacific inundation, the Sonoran sea was in open communication with the Mississippian sea. Subsequently, however, these two seas were separated by a greatly lengthened expanse of land.

Suwanee strait.—During the Eocene, Oligocene, and Lower Miocene central and southern Florida appeared as an island. The waterway between insular Florida and Appalachia, connecting the Atlantic and the Gulf of Mexico, Dall and Harris have named "Suwanee strait." The same opening undoubtedly existed during the Cretacic, but there is no evidence of it across Antillia-Appalachia until the time of the Lower Devonic. From thence into the Cambric the southern Mississippian sea again and again had faunas that are Atlantic or Poseidon in their origin. On this evidence rests the separation of Appalachia from Antillia in order to permit the Poseidon faunas passage across Florida into the Mississippian sea.

Sea of Tehuantepec.—At present North America and Central America are bound together by a narrow strip of land, the passes of which are not high above the sea. The geology of this region is known only along general lines. Honduras appears as an ancient land nucleus, to the north of which, in Guatemala and Chiapas, occur Pennsylvanic and Mesozoic deposits. As most of Mexico north of southern Oaxaca seems to have been land during the Paleozoic, and as certain of the faunas of the Mississippian sea must have entered the Mexico mediterranean across the syncline of Guatemala, this marine thoroughfare may be named the *Sea of Tehuantepec.*

Traverse basin.—See Mississippian sea.

Vancouverian sea.—This comprises the Pacific extensions across British Columbia, the character of which is that of an interior continental sea. The eastern edge of the land bounding it on the west seems to be represented by Queen Charlotte islands. Dawson[73] regards the area of this sea as a syncline; therefore there should be a land to the west parallel to Cascadia. For the present the definition of this bordering continental sea is obscure, but during the late Paleozoic, early Mesozoic, and the Tertiary it was subject to much volcanic activity. The Nicola formation of Triassic time alone has a thickness of 13,590 feet, nine-tenths of which are of volcanic origin.

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[73] G. M. Dawson: Bull. Geological Society of America, vol. 12, 1901, p. 73.

Paleozoic Lands, or Positive Elements

(See map, plate 49)

James D. Dana was apparently the first to point out the permanency of oceanic and continental areas. From the standpoint of a Laplacian[74] he stated the following in his paper "On the volcanoes of the moon," which appeared in 1846:[75]

> "On our globe the continents have to a very great extent been long free from volcanic action. A glance at a map of Asia and America will make this apparent. It is usual to attribute this almost total absence of volcanoes from the interior of the continents to the absence of the sea; but it is fatal to this popular hypothesis, that the same freedom from volcanoes existed in the Silurian period, when these very continents were mostly under salt water, a fact to which the widespread Silurian rocks of America and Russia testify. Over the *oceans*, on the contrary, all the islands excepting the coral, are igneous—and the coral may rest as we have reason to believe on an igneous base.
>
> "It is therefore a just conclusion that the areas of the surface constituting the continents were first free from eruptive fires. These portions cooled first, and consequently the contraction in progress affected most the other parts. The great depressions occupied by the oceans thus began; and for a long period afterward, continued deepening by slow, though it may have been unequal, progress. This may be deemed a mere hypothesis; if so, it is not as groundless as the common assumption that the oceans may have once been dry land, a view often the basis of geological reasoning.
>
> "Before the depression of the oceanic part of our globe had made much progress, the depth would be too shallow to contain the seas, and consequently the whole land would be under water. Is it not a fact that in the early Silurian epoch nearly every part of the globe was beneath the ocean? [What he has observed here is the Trenton inundation; it is the largest to which North America has been subjected.] . . . The depth of water over the continental portions would be very various; but those parts which now abound in the relics of marine life, were probably comparatively shallow, as amount of pressure, light, and dissolved air, are the principal circumstances influencing the distribution of animals in depth. . . . Here then we see reason for what has been considered a most improbable supposition, the existence of an immense area covered in most parts by shallow seas and so fitted for marine life.

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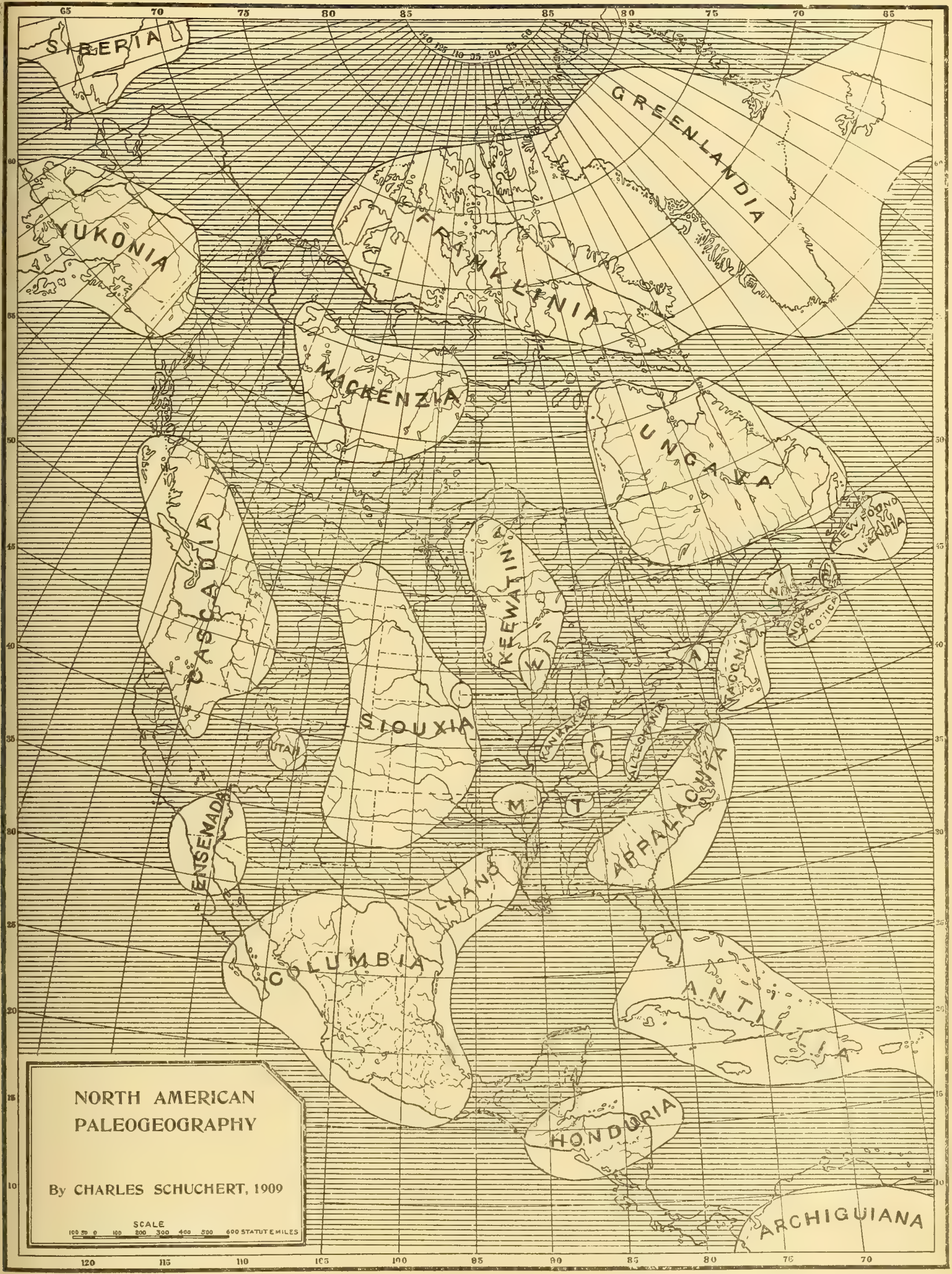
[74] According to the planetesimal hypothesis of Chamberlin and Salisbury, the permanency of oceanic and continental areas is also held, but the method leading to the origin of the oceans is different from those described by Dana. (See their Geology, vol. II, 1906, pp. 84-88, 106-111.)

[75] Dana: American Journal of Science, vol. 2, 1846, pp. 353-355.


SIBERIA
GREENLANDIA
YUKONIA
FRANKLINIA
MACKENZIA
UNGAVA
NEWFOUNDLANDIA
CASCADIA
KEEWATINIA
N.B.
NOVA SCOTICA
W
A
TACONIA
SIOUXIA
UTAH
KANKAKEE
C
ALLEGHANIA
APPALACHIA
ENSENADA
M
T
LLANO
COLUMBIA
ANTILLIA
HONDURIA
ARCHIGUIANA
NORTH AMERICAN PALEOGEOGRAPHY
By CHARLES SCHUCHERT, 1909
SCALE
600 STATUTE MILES

PALEOZOIC POSITIVE ELEMENTS

"If we follow the progress of the land, we find that with each great epoch there has been a retiring of the sea. . . . Subsequently, the progress on the whole was giving increased extent and height to the land and diminishing the area of the waters. Instead therefore of a bodily lifting of the continents to produce the apparent elevation, it may actually have been a retreating of the waters through the sinking of the ocean's bottom. The process however has not been a continuous one: for during each epoch . . . there have been subsidences as well as seeming and actual elevations, and various oscillations of the continental surface, from subaërial to submarine and the reverse.

"And why should not the ocean's bottom subside, as well as the land? [He states that there are 200 subsiding islands in the present Pacific (Dana, 1847: 94.)] What has given the continental portions of our globe their elevation, as compared with other parts, if not the unequal contraction of the whole?"

"Ruptures, elevations, foldings and contortions of strata have been produced in the course of contraction. The greater subsidence of the oceanic parts would necessarily occasion that lateral pressure required for the rise and various foldings of the Alleghanies and like regions" (1846: 352-355).

"If then, the typical form of a continent is a trough or basin, the oceanic border being raised into mountains; if these borders are so turned as to face the widest range of ocean; if the height of these border mountains and the extent of the igneous action along them is directly proportioned to the size of the oceans,—the Pacific, accordingly, being girt with great volcanoes and lofty mountains, while the narrower Atlantic is bounded by smaller heights and but few volcanoes; if, moreover, volcanoes characterize the islands of mid-ocean and not the interior of the continents: what is the legitimate inference?

"Most plainly, that the extent and positions of the oceanic depressions have some way determined, in a great degree, the features of the land; that the same cause which originated the one, impressed peculiarities on the other; that the two had a parallel history through past time—the oceanic depressions tending downward, the continents upward; in other words, that they have both been in progress with mutual reaction from the beginning of the earth's refrigeration. The continents have always been the more elevated land of the crust, and the oceanic basins always basins, or the more depressed land."[76]

We have seen how the lands or positive elements originated, and in the language of Willis[77] these are characterized as follows:

"The geologic characteristics of a positive element are deep denudation, an absence of sediments of critical periods, and the corresponding prolonged duration of the sum of unconformities. . . . They may have been depressed relatively to adjacent areas to some extent, but the algebraic sum of vertical movements has been upward, and has been positive as compared with other parts of the continent and the neighboring ocean bottoms. Whether they be regarded as horsts or protrusions resulting from radial elongation, their movement is positive, and they may fitly be called positive elements."

Late in Proterozoic time, or just previous to the introduction of the

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[76] Dana: American Journal of Science, vol. 22, 1856, pp. 338-339.

[77] Willis: Bull. Geological Society of America, vol. 18, 1907, p. 393.

Paleozoic continental seas, North America was certainly outlined, and was then even larger than it is at present. This fact is also noted by Walcott,[78] who states:

> "The continent was larger at the beginning of the Cambrian period than during any epoch of Paleozoic time. . . . The continent was not then new. . . . It was approaching the baselevel of erosion over large portions of its surface. . . . I strongly suspect . . . that ridges and barriers of the Algonkian continent rose above the sea . . . that are now buried beneath the waters of the Atlantic."

A survey of the Paleozoic paleogeography here submitted shows that the seas are of a continental character, for the marine waters of the four quarters of the northern hemisphere flow in on the depressed inland basins of the North American continent; further, that this vast land-mass has in the main always been bordered by high lands. The sediments of these seas are derived from the elevated areas of the continental mass and there was no "contribution of rock material from outside or aid from the ocean's waves or currents, either those of the Atlantic or Pacific. For the most part, therefore, the growth of the continent . . . may be said to have been *endogenous*. It began to be *exogenous* on the Atlantic side in the Cretaceous era" (Dana).

These facts and others stated on later pages prove that the North American continent in its entirety has always been essentially positive, and was a greater land-mass just previous to the introduction of the Cambric and the Siluric seas than it is now. Moreover, during the Paleozoic its surface was variously buckled and elevated, but never very highly, owing to the inwardly moving Atlantic, Gulf, and Pacific margins, thus giving rise to shallow or continental island studded seas. During the early Mesozoic the North American continent was again larger than it is at present, but in late Mesozoic time, long after the Sierra Nevada deformation, another great syncline was developed giving rise to a continental sea that did vast endogenous work along the entire eastern side of the Rocky mountains extending from the Gulf to the Arctic ocean. Finally, since the disappearance of this, the Coloradoan sea, the North American continent has had throughout almost its present size and the work of its marine waters has been exogenous, due to overlaps of the oceans.

As the North American continent now combines many positive elements that are particularly noticeable as separate elements during Paleozoic times, when the mainland appears rather as a series of varying large and small islands, it is thought advisable to give each component part a distinctive geographic name. These are here described in alphabetical order.

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[78] Walcott: Twelfth Ann. Rep. U. S. Geological Survey, 1891, p. 562.

Acadia.—An extensive marginal positive element with much volcanic activity, embracing the New England states, the maritime provinces of Canada, and Newfoundland. Its fundamental character was impressed upon it previous to Cambric times. During the Paleozoic it was variously dismembered by marine waterways, and was subjected to much elevation and erosion, apparently far more than Appalachia. The greater and more essential portion of this land was first described by Dana[79] as the "Acadian range." He defined it as "commencing in the western part of northern Newfoundland, east of White bay, and extending thence to Saint George bay and cape Ray in southwestern, and beyond over eastern Nova Scotia." According to the maps of the present writer, three lands are here involved, which are named in this memoir Newfoundlandia, Novascotia, and Bretonia. The term could, of course, be used for these lands when united, as is often the case in the Paleozoic, but the writer prefers to make use of Acadia in the widest sense, as defined above. Acadia also includes Dana's "Mount Desert range," elsewhere described.

Acadia was composed of a number of subelements, which may be defined as follows: *Taconia*[80] embraced more or less of New England and is the largest of the subelements of Acadia. Apparently the greater part of it had been land since the Ordovicic. It included the New Hampshire range and the southern portion of Dana's Mount Desert range. *Newfoundlandia* may be applied to the larger southern and most positive portion of the island, the northern peninsular region being more often a part of Ungava. Dana[81] determined this land as the "Central-Newfoundland range," and described it as "extending over a broad region east of the Exploits River valley, to the east side of Exploits bay." *Novascotia* may be used for the province by this name, the northwestern portion of which was variously overlapped by the Acadian trough. Dana included this land in his Acadian range, and it is his "Nova Scotia protaxis."[82] *Newbrunswickia* represents a small subelement at the northeast of the province of New Brunswick. Dana regarded this land as part of his Mount Desert range. *Bretonia* stands for the smallest subelement of Acadia, comprising the counties of Inverness and Victoria, Cape Breton island. It is also included in Dana's Acadian range mentioned above.

Acadian range.—See Acadia.

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[79] Dana: American Journal of Science, vol. 39, 1890, p. 379. Bull. Geological Society of America, vol. 1, 1890, p. 37. Manual of Geology, 1895, p. 444.

[80] Grabau: Journal of Geology, Chicago, vol. 17, 1909, p. 221.

[81] Dana: American Journal of Science, vol. 39, 1890, p. 380.

[82] Dana: Bull. Geological Society of America, vol. 1, 1890, p. 37.

Adirondackia.—See Laurentia.

Alleghania.—A narrow, slightly positive element extending from southern Kentucky into New York, having the strike of the Appalachian folds. It represents the western part of the Alleghany plateau of physiographers (Lippincott's Gazetteer, 1906: 44). During times of general inundation it is probable that this area was a submerged bank, rather than a land. It was the western edge of the subsiding Appalachian synclinorium, and probably had its origin at the time of the Cincinnati uplift.

Antillia.—This element embraced the Greater and Lesser Antilles and the Bahama islands. If there is any Paleozoic sedimentary history of this region it is unknown, but all writers treating of this subject agree in assuming that during the Paleozoic this region was land. Willis[83] regards it as the southern extension of Appalachia, the view also of Frech,[84] who calls it "Paleoappalachia." At different times, however, Antillia appears to have been separated from Appalachia by Suwanee strait, as indicated by the distinct Atlantic faunas that enter the Mexico embayment during this time. This fact furnishes the necessity for the term Antillia.

Appalachia.—This name has long stood for a marginal positive element of very ancient origin, comprising most of the Atlantic states from southern New Jersey to eastern Alabama. While land had existed in this area continuously since the Cambric, there is no evidence that Appalachia was subjected to the same amount of elevation as Acadia. However, the middle and southern portions apparently extended far into the Atlantic during the Paleozoic—a condition maintained during the greater part of Mesozoic time by the decided rejuvenation of Appalachia during the Appalachian revolution. In the north the Atlantic repeatedly crossed Appalachia, and in the Ordovicic had a short embayment down what is now the Piedmont plateau to southern Virginia. Appalachia, being a bordering positive element, was nevertheless devoid of volcanic activity during the Paleozoic, as far as its present area is concerned. While this fact is in harmony with what is known regarding most of the lands contiguous to the Atlantic ocean, yet as Appalachia was subjected to much lateral pressure during the late Paleozoic it seems as though some volcanic action must have then existed. Does this condition signify that Appalachia extended farther into the Atlantic than is generally supposed?

Appalachia was first defined by Dana in 1856.[85] He states:

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[83] Willis: Bull. Geological Society of America, vol. 18, 1907, p. 394. Journal of Geology, Chicago, vol. 17, 1909, p. 206.

[84] Frech: Lethæa geognostica, 1901.

[85] Dana: American Journal of Science, vol. 22, 1856, pp. 319, 344. See also Manual of Geology, 1874, p. 150. Bull. Geological Society of America, vol. 1, 1890, p. 36. Manual of Geology, 1895, p. 443.

> "The region toward the Atlantic border, afterward raised into the Appalachians, was already then, even before the Lower Silurian era closed, the higher part of the land" (319). "We hence learn that in the evolution of the continental germ, after the appearance of the Azoic nucleus, there were two prominent lines of development, one along the Appalachian region, the other along the Rocky Mountain region—one, therefore, parallel with either ocean. Landward, beyond each of these developing areas, there was a great trough or channel of deeper ocean waters, separating either from the Azoic area" (344).

The name Appalachia was given by Williams.[86] The term Appalachians was applied to these mountains by the Spaniards under De Soto, the word being derived from the neighboring Indians.

Archiguiana.[87]—This element comprises Venezuela and Guiana, and at times, according to Von Ihering, the Antilles also. Suess has likewise defined this very ancient shield. In its history it is comparable to Laurentia, since through the action of the Pacific ocean the accretions of Paleozoic South America formed around its southern and western sides, while the effects of the Caribbean were slight, having practically the same value as those of the Arctic ocean on Laurentia.

Bretonia.—See Acadia.

Cascadia.—Dana[88] thought that there might be an ancient protaxis along the Sierra Nevadas, the Cascades of Oregon and Washington, and the ranges of western British Columbia. According to G. M. Dawson,[89] the Gold ranges were an old protaxis. This entire region exhibited no known Paleozoic sediments until Carbonic times, and it is represented as land in the author's map. Cascadia was a bordering positive element, and owing to the pressure and subsidence of the vast Pacific ocean it had at different times been subject to great volcanic activity. The first seismic period was coincident with the late Devonic of California, but during the late Paleozoic and early Mesozoic volcanic action appears to have been as great as in Cenozoic time.

Various geologists have included Cascadia in the Rocky mountain or Cordilleran land, the southern end of which was pointed out by King;[90] latterly Willis[91] has defined this as the Pacific element.

Central Newfoundland range.—See Newfoundlandia, under Acadia.

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[86] Williams: American Journal of Science, vol. 3, 1897, p. 397. See also Willis: Bull. Geological Society of America, vol. 18, 1907, pp. 394, 398.

[87] Von Ihering: Archhelenis und Archinotis, 1907, p. 111.

[88] Dana: Bull. Geological Society of America, vol. 1, 1890, p. 45.

[89] Dawson: Ibidem, vol. 12, 1901, p. 84.

[90] King: U. S. Geological Exploration, 40th Parallel, vol. 1, 1878, p. 247.

[91] Willis: Bull. Geological Society of America, vol. 18, 1907, pp. 396, 398.

Cincinnati axis.—This is represented by the Cincinnati geanticline of Dana,[92] or the Cincinnati uplift of earlier geologists—Newberry and Safford—and the Cincinnati plateau of Williams.[93] This low parma had the strike of the Appalachian folds and was at times overlapped by the sea, in which case either end, or both, may have persisted as islands. The northern portion will here be referred to as *Cincinnatia* (Cincinnati island, Dana[94]) and the southern end as *Tennesseia* (Tennessee island, Dana). The uplift appeared in middle Ordovicic times, and was a marked topographic feature of the Mississippian sea since that time. Cincinnatia may have been completely submerged in early Mississippic time, since which it has been land continuously, and today has greater elevation than at any period of the Paleozoic.[95]

Columbia.—The government geologists of Mexico believe that most of their republic was land during the Paleozoic, for such strata occur only along the southern boundary in Chiapas, more extensively along the northern limits, and especially in Sonora. Most of Mexico is deeply buried beneath Mesozoic sediments, and it is in the south and west alone that the metamorphic formations of supposedly pre-Paleozoic age appear at the surface. During the Paleozoic this republic extended northeastward through the Llano region of Texas into Louisiana and Arkansas. To this "rather neutral element" may be applied the term *Llano* of Willis.[96] Columbia is often continued as an unbroken land far to the north, then embracing part or all of Siouxia.

Ensenada.—The history of southern California, northern Baja California, and western Arizona is very obscure, but geologists surmise that this region was land throughout the greater part of the Paleozoic and possibly until the Pennsylvanic. The elemental name is taken from the town of Ensenada de Todos Santos, Baja California.

Franklinia.—See Laurentia.

Greenlandia.—See Laurentia.

Honduria.—A very persistent positive pre-Paleozoic element, the nucleus of which is Honduras. Its geological history seems to be connected with that of Antillia. To the north, in Guatemala, both Paleozoic and Mesozoic strata have been found, while to the south, in Nicaragua, Mesozoic and probably Paleozoic sediments are reported.

Kankakeia.[97]—A low, irregular parma trending "northeast from southern Illinois to the region of the Kankakee river . . . striking northerly through the western part of the lower peninsula of Michigan." It also seems to have originated with the movements recorded in the Taconic revolution, and this parma is often in connection with Missouria.

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[92] Dana: Bull. Geological Society of America, vol. 1, 1890, pp. 41, 42.

[93] Williams: American Journal of Science, vol. 3, 1897, p. 394.

[94] Dana: Manual of Geology, 1895, pp. 537, 633.

[95] Schuchert in Eastman: Ann. Rep. Geological Survey of Iowa, vol. 18, 1908, map.

[96] Willis: Bull. Geological Society of America, vol. 18, 1907, pp. 394, 397, 398.

[97] Schuchert: American Geologist, 1903, p. 150.

Keewatinia.—See Laurentia.

Keweenaw continent.—Walcott[98] proposed this name in 1886 "for the land that existed on the North American continental plateau at the beginning of Cambrian time." "The name is now adopted for the continent at the beginning of Cambrian time."

Laurentia.—"The germ or nucleus of the future continent" (Dana).[99] "Great northern Nucleal" (Dana).[100] "Canadian shield" (Suess).[101] The western end of Unger and Heer's, and Hull's (1885) Atlantis. The name Laurentia was given by Williams.[102]

As early as 1856 Dana made the following statement in regard to Laurentia:

> "The earliest spot or primal area will be that of the Azoic rocks, the first in the geological series. Such an area extends from Northern New York and Canada, northwest to the Arctic Ocean, lying between the line of small lakes (Slave, Winnipeg, &c.) and Hudson Bay. East and west, it dips under Silurian strata, but it is itself free from superincumbent beds., [We now know that the Ordovicic strata covered most of this area, but subsequently it appears that the sea did not again invade the western end of the shield.] . . . It has apparently held its place with wonderful stability, for it is now, as probably then, not far above the ocean's level.
>
> "This area is central to the continent; and, what is of prominent interest, it lies parallel to the Rocky mountains and the Pacific border, thus proving that the greater force came from that direction in Azoic times, as well as when the Rocky mountains were raised. Thus this first land, the germ or nucleus of the future continent, bears in itself evidence with respect to the direction and strength of the forces at work. The force coming from the Atlantic direction has left comparatively small traces of its action at that time. Yet it has made its mark in the Azoic stretching through Canada to Labrador, in the dip and strike of the New York Azoic rocks, in the direction of the channel of the Saint Lawrence and the northwest coast of Lake Superior, and probably also in the triangular form of Hudson's Bay. Against this primal area, as a standpoint, the uplifting agency operated, acting from two directions, the Atlantic and the Pacific; and the evolution of the continent took place through the consequent vibrations of the crust, and the additions to this area thereby resulting" (Amer. Jour. Sci., vol. 22, 1856, 341, 342).

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[98] Walcott: Twelfth Ann. Rep. U. S. Geological Survey, 1891, pp. 540, 541.

[99] Dana: American Journal of Science, vol. 22, 1856, p. 342.

[100] Dana: Manual of Geology, 1874, p. 150.

[101] Suess: Antlitz der Erde, vol. 2, 1888, pp. 42-58. Translation in Sollas, vol. 2, 1901, p. 254. Willis: Bull. Geological Society of America, vol. 18, 1907, pp. 393, 397.

[102] Williams: American Journal of Science, vol. 3, 1897, p. 394.

> "Thus the enlargement went on to the southward, each period making some addition to the main land, as each year gives a layer of wood to the tree. Not that this addition was free from oscillations, causing submergences, for these continued long to occur; but the gain, on the whole, was a gain" (343, 344).
>
> "The Azoic nucleus of North America, spreading southward, formed a peninsula in Northern New York [Adirondackia]. Even this bend in the nucleus continues in the finished continent, for New England has the same outline. Its east and south coast-lines are but a repetition of the east and south coast-lines of the old Azoic peninsula. This exact copying of the nucleus by the growing continent proves, better than all other evidence, the grand fact that the progress has been through oscillating forces acting against the stable Azoic nucleus, and also that the system of evolution has been under profound law" (Dana, Manual of Geology, 1863, 737).

Laurentia was the most persistent positive element of North America, large portions of it having been land continuously, and around its Arctic, western, and southern sides were deposited Paleozoic or Mesozoic sediments. In the west and south great parts were inundated in Ordovicic and Siluric times. With the Devonic the "shield" became decidedly larger, and increased still more extensively in the Mississippic. The Hudson bay depression was of very early origin, appearing for the first time in the middle Ordovicic, when it was a far larger continental sea than at present. From the close of the Siluric until late Tertiary times no marine waters appear to have invaded this region, and from the beginning of the Paleozoic it seems to have been devoid of volcanic activity. The southern portion of Davis strait also gives evidence of being of very ancient origin, for the Ordovicic sea must have extended across southern Baffin Land, thus connecting the northern Atlantic with the interior Hudson sea. Early in the Siluric, Ungava appears to have united with Baffin Land, establishing a land barrier against further Atlantic overlaps until modern times.

Laurentia was the western end of the *Great North Land* of the Paleozoic and Mesozoic, sometimes erroneously called Atlantis. Nearly all geologists and zoogeographers are agreed that it extended across Greenland, Iceland, Norway, and united with the "Baltic shield," best seen in Finland.

Laurentia is readily divided into seven subelements that at times are separated from one another by shallow sea-ways, but are all comprised in one continuous land-mass subsequent to the Siluric. These subelements are as follows: *Greenlandia*, which embraced present Greenland, was from the close of the Siluric until late Cretacic times united with *Franklinia*, when Davis strait was extended to Disco and Nugsuak. Along its northeastern shores are Paleozoic and Mesozoic strata, showing that the Arctic ocean here lapped the Great North Land. Southeastern Greenlandia is devoid of all fossiliferous sediments. Franklinia includes the Franklin archipelago (Arctic archipelago of Willis, 1907, 393). During parts of Ordovicic and Siluric times this region was under the sea, but subsequent to the late Siluric only its northern region was invaded by the Arctic ocean of later Paleozoic times. In reality Franklinia was but a part of Greenland. *Ungava* was decidedly positive along its eastern and western portions, but in the northern area the Ordovicic and Siluric seas slightly overlapped, while during the Paleozoic its southern border was variously inundated, this being especially true along the Gulf of Saint Lawrence. *Keewatinia,* to the southeast of Hudson bay, extended from southern Keewatin through Ontario to and including peninsular Wisconsia. As an independent land surrounded by marine waters, it persisted only during Ordovicic and Siluric times. If this area was ever greatly submerged, this occurred in the north; in the south and only in middle Cambric times did the Mississippian sea isolate *Wisconsia* as an island. The latter subelement was first referred to by Chamberlin,[103] then by Dana,[104] as the Michigan island. In 1907 Willis[105] termed it "the isle of Wisconsin." *Adirondackia* (Adirondack area, Dana, 1874, 150) appeared as an island during various times in the early Paleozoic, and may have been completely inundated in the Utica. Later neither the waters of the Mississippian sea nor those of the Saint Lawrence sea ever completely invaded the promontory. The "Frontenac axis" of Ami[106] is embraced in western Adirondackia. *Mackenzia* was an extensive flat land appearing as a separate element only during parts of Ordovicic and Siluric times.

Llano.—See Columbia.

Mackenzia.—See Laurentia.

Missouria.—This is the same as the "Missouri island" of Dana[107] and "Ozarkia" of Ulrich.[108] It included the Ozark Mountain area of Missouri and Arkansas and was almost continuously positive, for only in late Cambric (Ozarkic) time was it entirely beneath the sea, but it was again nearly submerged in the later Mississippic. Missouria was often in connection with the greater western land Siouxia.[109]

Mount Desert range.—This is defined as "commencing near Chaleur bay, on the gulf of Saint Lawrence, and continued southwestward through New Brunswick to the coast of Maine, where it includes the Mount Desert region, and thence into eastern Massachusetts between Boston and Worcester, and probably into Connecticut." The present writer believes that two distinct land-masses are here involved. In this paper the northern one is called Newbrunswickia, while the regions within the United States are included in Taconia. See Acadia.

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[103] Chamberlin: Geological Survey of Wisconsin, vol. 1, 1873, p. 119.

[104] Dana: Manual of Geology, 1874, p. 150.

[105] Willis: Bull. Geological Society of America, vol. 18, 1907, p. 393.

[106] Ami: Ibidem, vol. 13, 1903, pp. 517-518.

[107] Dana: Manual of Geology, 1895, p. 537.

[108] Ulrich: Professional Paper no. 24, U. S. Geological Survey, 1904, p. 111.

[109] Also see Willis: Bull. Geological Society of America, vol. 18, 1907, pp. 395, 398.

Newbrunswickia.—See Acadia.

Newfoundlandia.—See Acadia.

New Hampshire range.[110]—Dana extends this range "from the borders of Maine and Canada, through New Hampshire and Massachusetts into Connecticut, making the east side of the Connecticut" trough. According to the maps of the writer, this protaxis of Dana is in general the bounding western region of Acadia or Taconia. See Acadia.

Novascotia.—See Acadia.

Ozarkia.—See Missouria.

Siberia.—Almost nothing is known of the geology of eastern Siberia, and it is represented as land in the present maps to obviate drawing in a sea where none are as yet known to have existed.

Siouxia.—An extensive Paleozoic land embracing the greater part of the Great Plains area of the United States. At times it was divided by *Montana strait* into northern and southern subelements. Its western border is established along the Front range of Colorado and New Mexico by the eastward thinning of the Paleozoic formations combined with the geographic position of the floral horizons of the Ouray basin. In Wyoming the absence of certain Paleozoic deposits also indicates the presence of this land. To the east the land is again seen plainly in the Sioux quartzite of northwestern Iowa, while to the southeast it was often in direct connection with Missouria, as proved by the isolated faunas of Oklahoma. At times Siouxia was also united with Columbia, the extensive land then separating the Mississippian and Cordilleran provinces, and at such times the latter name should take precedence.

Taconia.—See Acadia.

Tennesseia.—See Cincinnati axis.

Ungava.—See Laurentia.

Utah.—A small positive Paleozoic element, constant in eastern Utah, but spreading variously at different times, and was often but a western extension of Siouxia. When of smallest area it lay between the Great basin and Ouray basin. Willis included Utah in his "Rocky Mountain element" (1907, 398), also called "Colorado" (1907, 395, 396).

Wisconsia.—See Laurentia.

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[110] Dana: American Journal of Science, vol. 39, 1890, p. 379.

Yukonia.—Named for "the Yukon plateau. . . . The central area may represent a positive element, the backbone of Alaska, compressed between the thrusts from the Pacific and Arctic basins" (Willis, 1907, 397, 398).

DISPLACEMENTS OF THE STRAND-LINE

EMERGENCES AND TRANSGRESSIONS

That the land moves up and down in causing the appearance and vanishing of seas is the widely accepted view of geologists, but that a submergence of the land may be due to a change in the hydrosphere without the inundated land having moved at all is held by few. Dana, as long ago as 1863,[111] called attention to the fact that an emergence of the land may be due to a subsidence of the oceanic areas. He states:

> "As all parts of the earth, oceanic as well as continental, must have participated in the changes of level, the water-level was ever fluctuating like the land level; and hence it is not safe to measure the latter always by the former, as is too commonly done. Many of the apparent elevations may have been due to a deepening of the oceanic basin . . . and some of its apparent subsidences may have been caused by an elevation of its bottom. It is probable that at least 1,000 feet of the height of the continents . . . has arisen from the increase in the depth of the ocean which took place during the successive Paleozoic, Mesozoic, and Cenozoic eras."

Suess has given a great deal of thought to the transgressions of the sea, and has concluded that most of these can not be explained by subsidence of the land. In his valuable work, Das Antlitz der Erde, the first two volumes treat more or less directly of the movements of the lands and seas. As his conclusions are of the greatest value in seeking for an explanation of the various transgressions that have occurred in North America, it is deemed necessary to introduce them here. The student, however, should also consult the original work, which is now more accessible in the English translation by Sollas and Sollas, entitled "The face of the earth."

> "It is usually assumed that the surface of the ocean is everywhere of equal elevation, that is to say, that every part of it, and consequently every part of its coast-line, is equally distant from the center of the earth. But this assumption . . . can not be maintained. . . . It must be considered as proved that the mass of the continents exerts a considerable attraction upon the ocean and that consequently the surface of the sea rises toward the mainland. . . . The difference of elevation in meters amounts, according to Fischer, to about 122 times the difference of the number of oscillations of the pendulum in twenty-four hours. This would give, with a difference of nine oscillations, for example, between an oceanic island and the coast, an actual difference in ele-

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[111] Dana: Manual of Geology, 1863, p. 723.

vation of about 1,100 meters, or 3,609 feet. The shores of the continents, and the continents themselves, consequently appear much lower to the eye than is actually the case; the attraction of the sea to the land conceals to a great extent the contrast which really exists between continent and ocean. Listing attempted to determine the effect of the attraction in a large number of places and found: London, 118 meters; Paris, 268; Berlin, 37.7; Königsburg, 92.6; island of Marañon (Brazil coast), 567; Bonin island, — 1,309; Saint Helena, — 847; Spitzbergen, — 217. [See also Dana: Manual of Geology, 1895, page 346. Helmert has since shown that the calculations of Listing are based on erroneous formulæ and objectionable postulates. His recalculations have shown that all irregularities of the geoid may not exceed the total of 200 meters. See Krümmel, Handbuch der Oceanographie, 1907, p. 53.]

"The significance of this fact becomes apparent if we suppose the attraction to cease. That portion of the ocean which is now drawn up over the margin of the continents would subside, many of the bays which deeply indent the continents would be laid completely dry; the continents would gain somewhat in extent, and a great deal in height and continuity. But while the continents would gain in prominence, the ocean would gain in depth."

"Carpenter, as we have said, estimates the mean height of the continents at 1,000 feet at most, Krümmel at 440 meters; the example taken to show the influence of attraction gave 1,100 meters for the rise of the ocean, that is to say, more than twice, indeed nearly three times, the higher estimate for the mean height of the continents. Even supposing these figures to be exceptional, and the mean result of attraction to sink to less than one-half the figure quoted (a point on which I lack means of forming an opinion), there still remains ground for a comprehensive correction of prevailing views" (I: 2, 3).

Suess then discusses *dislocations,* contrasting them with *transgressions,* as follows:

"A dislocation, whether it consists in folding or faulting, is limited to a definite mountain system, often even to a very small part of it; a transgression extends over a large part of the earth's surface. The intensity of a dislocation is subject to very rapid local variations; in a transgression, difference of intensity, within the limits of a single region, can hardly be distinguished, and a transgression may often extend over large areas in complete concordance with the underlying beds."

"Under various forms the theory has long been maintained that along with the movements of the earth's crust, changes take place in the form of the surface of the sea. The remarkable extension of certain transgressions leads us to return to this view. A close investigation of the most recent events, such as are indicated by ancient shorelines situated above the existing sea-level, can alone lead to definite results. But even a hasty consideration of such strand-lines suffices to show their complete and absolute independence of the geological structure of the coast. In Italy the lines of former sea-levels are met with on the various promontories of the Apennines in undisturbed horizontality, here on limestone, there on the ancient rocks of Calabria, here once more on the ash cone of Aetna. The complete absence of any relation between the ancient shore-lines and the structure of the mountains may be proved by hundreds of examples. But the supposition of a uniform elevation or depression of a continent, so complicated, and divided into so many fragments, without any mutual displacement of the parts—a supposition necessary to explain the horizontal course of these lines on the separate portions of a mountain complex—cannot be brought into harmony with our present knowledge of the structure of the mountains themselves. Thus this circumstance, too, leads us to infer independent movements of the sea, that is to say, changes in the form of the hydrosphere" (I: 14, 15).

In 1848 "Robert Chambers introduced a new phrase; he spoke neither of elevation nor of subsidence, but only of 'changes of relative level,' or, as we shall say, *displacements of the strand-line.*

"With the adoption of these neutral terms it at once follows that the displacements of the strand-line in an upward direction must be described as *positive,* those in a downward direction as *negative,* since this is the terminology universally employed by all oceanographers and in all operations of water gauging. . . . In this work therefore the older term *elevation of the land* will be replaced by *negative displacement of the strand-line* and *subsidence of the land* by *positive displacement of the strand-line*" (II: 24).

"Great and general negative movements are from time to time produced by the formation of fresh oceanic abysses, or by the addition of new areas of subsidence to abysses already in existence, and it is important to bear in mind that movements of this kind surpass all others in importance" (II: 27).

"As soon as we recognize the Ocean basins as sunken areas, the continents assume the character of horsts, *and the wedge-like outlines of Africa, India, and Greenland, all pointing towards the south, find their explanation in the conjunction of fields of subsidence which reach their greatest development in the same direction.*"

"*The crust of the earth gives way and falls in; the sea follows it.* But while the subsidences of the crust [= lands] are local events, the subsidence of the sea extends over the whole submerged surface of the planet. It brings about a general negative movement.

"As a first step toward an exact study of phenomena of this kind, we must commence by separating from the various other changes which affect the level of the strand, those which take place at an approximately equal height, whether in a positive or negative direction, over the whole globe; this group we will distinguish as *eustatic movements*" (II: 537, 538).

Suess then surveys the various major transgressions of the sea and the emergences of the land, nearly all of which are recorded in the American continent. He concludes as follows:

"This recapitulation shows that *the theory of secular oscillations of the continents is not competent to explain the repeated inundation and emergence of the land.* The changes are much too extensive and too uniform to have been caused by movements of the earth's crust. The middle Cretaceous transgression presents itself on the Amazon, the Athabasca, the Elbe, the Nile, the Tarym, and the Narbada, in Borneo and Saghalien, and on the Sacramento; it marks a general physical change which affected the whole surface of the planet. In this lies the explanation of the remarkable fact that it has been found possible *to employ the same terminology to distinguish the sedimentary formations* *in all parts of the world.* This would have been impossible if the limits of the formations had not been drawn by natural processes simultaneously in operation over the widest areas.

"It has been fortunate for stratigraphical geology that its earliest development took place in England, a region where the frequency of gaps in the stratified series neither rises above nor falls below the mean, a region which has at times been submerged beneath the sea, at others covered by fresh-water lakes or left exposed as dry land. . . . *The limits of the formations established by William Smith and his successors correspond for the most part with negative phases.* . . .

"In this also we find an explanation of the difficulties which were encountered in correlating the stratified series where it attains its complete marine development, as in the eastern Alps, with the succession established in England. In this again we recognize the source of the opinion expressed by many eminent investigators to the effect that this succession stands in relation to certain cycles, *i. e.*, a perpetually recurring alternation produces a periodic return of similar conditions.

"As to the precise nature of these phenomena we can only hazard conjectures. . . . The analysis of the Rhaetic series in the Alps shows that the positive movement, which carries the Rhaetic shore further and further outward till it finally extended across a large part of central Europe into the north of Scotland, must have been *oscillatory.* . . . There can be no doubt that the evidence afforded by the Rhaetic series and by the Purbeck is strongly in favor of numerous subsidiary oscillations. Oscillations of greater importance may be recognized with certainty, such, for instance, as those which caused the stages of the Lias to extend in transgression, some to a greater, others to a less distance. [Described in detail in II : 260-277. See also Ulrich's paper in this volume, which describes the many oscillations of the American Ordovicic.] . . . These represent in other words secondary cycles within the primary. The principal phases or the primary cycles reveal themselves with even greater definiteness.

"But it is a striking fact that in the best known of these primary cycles the positive phase is of much greater duration than the negative phase which follows it. . . .

"Finally, the regular and uniform character of the movements may be recognized from the concordant superposition of the more recent beds on those of much greater age. Of this there are numerous examples. Murchison, in describing the recent marine beds with Arctic shells at Ust-Waga, on the Dwina, has pointed out their absolutely conformable superposition on the horizontal Permian sediments ; he has also shown how at other places the latter sediments rest in perfect concordance on much older beds, so that the stratigraphical relations offer no hint of the great gap which occurs at the line of contact [= disconformity]. That this should be the case may well be cause for astonishment, for some degree of erosion, weathering, or other alteration of the surface must have occurred in the interval, and I can scarcely help thinking that even in this case some kind of erosion, though feeble perhaps in its effect, must at one time have been active.

"The question now presents itself as to whether these positive movements were likewise eustatic.

> "Material is continually being carried into the sea. . . . The oceanic regions are filled up slowly but without intermission, and their waters in consequence are gradually displaced" (II, 540-543). "Every grain of sand which sinks to the bottom of the sea expels, to however trifling a degree, the Ocean from its bed" (II: 555).
>
> "*The formation of sediments causes a continuous, eustatic positive movement of the strand-line.*
>
> "We are thus acquainted with two kinds of eustatic movement; one, produced by subsidence of the earth's crust, is spasmodic and negative; the other, caused by the growth of marine deposits, is continuous and positive" (II: 543-544).

In regard to the traces of the elevated horizontal shorelines occurring along most modern coasts, Suess states that

> "the more recent movement was an accumulation of water towards the equator, a diminution toward the poles, and as though this last movement were only one of the many oscillations which succeed each other with the same tendency, *i. e.*, with a positive excess at the equator, a negative excess at the poles" (II: 551).

In conclusion, Suess says:

> "In all probability the Ocean is subject to an independent movement which in the course of long periods causes an alternation of positive and negative phases at the equator. We shall be able to discuss this oceanic movement with greater certainty when the stratified series in high latitudes is better known, and when we are able to clearly distinguish the terraces formed by glacial lakes from those of marine origin. These great oscillations are not, however, cumulative in time; on the contrary, they are compensatory. The persistent continuance of a continental surface is in the main the result of local subsidences of the earth's crust, which time after time open up fresh abysses for occupation by the sea, and lower the general level of the strand. Every eustatic negative movement of this kind . . . induces a heightened eustatic positive movement. . . . The effect of eustatic subsidences and the deposition of sediments is cumulative, and in the course of geologic periods the eustatic negative movements obtain the predominance. In this matter the folding of the mountain chains plays only a secondary part" (II: 553).

PALEOZOIC EMERGENCES AND SUBMERGENCES

General discussion.—From the preceding pages it may be learned that there are periodic recurrences of extensive emergences of the continents and that each one is later invaded or transgressed by continental seas of greater or less extent. The emergences mature far more rapidly than the transgressions. The former are thought to be due to the periodic subsidences of the oceanic bottoms, while the cause of the transgressions is not so clear. It is concluded, however, that the unloading of the combined continents into the seas is of primary importance in this connection.

With each period of marked sinking of the oceanic areas the strand-line becomes negative and everywhere recedes to a lower level around the continental horsts. The lands then appear to stand higher. The continents therefore attain their elevation through two causes: (1) Low lands over vast areas, due to the negative eustatic character of the strand-line, and (2) a more or less high altitude resulting locally from the tangential lateral thrusts of the oceans or vertical movements due to isostatic readjustments. The smaller invasions made by the sea may therefore be caused by lands produced by tangential thrusts, such movements being apt to form synclines along the inner sides away from the oceans, or the water may vary in local distribution, owing to its being attracted by the land-masses. Further, as the detrital material from the land is unloaded irregularly and locally into the continental seas, the submergences may be locally accentuated. There are, therefore, various types of continental seas, and these may be named and defined as follows:

Attracted continental seas.—During times of decided emergence due to the greater altitude and extent of the land-masses, the oceans may be drawn up the sides of these elevations several hundred feet, thus causing their margins or preëxisting depressions to be flooded. Such seas are met with after periods of actual elevation or eustatic negative movements. The resulting seas are small, and such are thought to be most frequently present in the Saint Lawrence sea.

Synclinal continental seas.—During recurrent periods of unrest the oceans thrust the margins of the continents inward and away from their areas. In the early stages of such movements broad and low folds are produced, which together make synclinoria along the inner sides of the mass thus disturbed, the folds being most numerous, higher, and closer together toward the ocean. Therefore the deepest continental troughs appear immediately at the base of such lands; the sea flows into them and makes long but narrow waterways. In the developmental stages of such a synclinorium the sea is at first apt to be broader and shallower. As the folds are successively accentuated by the subsequent thrusting, the water areas not only become deeper, but also more complex; hence a series of troughs may finally appear that may or may not be in communication with one another. The Appalachian and Saint Lawrence seas, with their sinking Lenoir, Chazy, and Levis troughs, are good examples of such seas. The Appalachian and Great Basin synclines had each finally subsided in certain local areas to a maximum of at least 30,000 feet.

Aggrading continental seas.—Being decidedly the areas of loading, continental seas are therefore aggrading seas; they are rarely degrading. Great quantities of detrital matter are transferred by the rivers to these seas, causing them either to spill over and inundate the other lands or causing their bottoms to subside. The strand-line is thus constantly affected either in a positive or a negative manner. In fact, this alternate loading and sinking explains the irregularity, at least, in the oscillatory nature of all continental seas. During a period of loading the waters are more and more displaced and submerge wider areas of land. If no subsidence of the sea-bottom takes place the basin will eventually become completely filled and all its water dispersed and added to other marine seas, thus causing the strand-lines to become positive. During a period of subsidence, however, the water is naturally contracted, and for a time parts of the former littoral region are exposed. In this way the strand-lines of aggrading seas are continually affected and made slightly positive or negative.

Again, if an area which is rapidly loading in vast quantities is constantly subsiding, there will result either some isostatic compensation in the way of land-making elsewhere, or where there is no compensation the entire adjacent areas will be dragged down. In the latter case, if such an area of a continental sea is close to the ocean the land barrier will be submerged, allowing communication between the two marine bodies of water. This is thought to have been the case during the deep subsidence of the New York basin, where every now and then the Atlantic has access to the Appalachian trough. In this region, either periodic isostatic compensation appears to have been operative or the tangential thrusting of the Atlantic ocean has repeatedly renewed the land barriers, which in the end were not only eroded, but again dragged down and submerged. Throughout the Paleozoic there was almost constant subsidence in the Mexico embayment, and the isostatic compensation must therefore have been farther removed than in the case of the New York basin. The Mississippian sea is an excellent example of an aggrading sea.

The "transgressive seas" are likewise aggrading seas, yet they owe their distinctive character not to minor local fillings, but to the combined deposits of all marine waters; also to the united effects of all the isostatic compensation having an upward movement, such as land-making and the elevation of the ocean-bottom as well.

Transgressing continental seas.—These bodies of water, which are due to a general eustatic elevation of the strand-lines (eustatic positive strand-lines), are the great continental seas that more or less simultaneously affect all continents. They are slow in attaining their maximum expansion, but vanish fairly rapidly following the periodic shrinkage of the earth, which naturally exerts more influence on the oceanic areas than on the lands. The migratory reëxpansion of these seas is due to the combined unloading of the continents into the marine waters, with the added effect resulting from the settling back of the elevated continental borders. Probably there are also other causes, one of which may be the local raising of oceanic bottoms. Suess has well said: "Every grain of sand which sinks to the bottom of the sea expels, to however trifling a degree, the ocean from its bed." If the present continents above sealevel were unloaded into the ocean, the strand-line would become positive to the extent of 650 feet. Such a displacement of the sea would inundate North America in areal extent and distribution not unlike the submergence caused by the Siluric transgression, the third most extensive flood on this continent.

With these definitions as a foundation, the various emergences and submergences of the North American continent will now be described. A marked period of emergence combined with one of decided submergence completes a cycle of time, and according to the principle of diastrophism establishes a geologic system or period that may be recognized in all lands affected by inundations. As this subject will be discussed elsewhere, only the systematic names of the new classification will be here introduced.

Laurentide revolution.—This was one of the "critical periods" of the earth when the seas were withdrawn from North America for a very long time. During this interval, of which only the later or eroding portion is known, the continent was larger than at present, possibly as great as at the close of the Paleozoic, or even greater than at that time. It was a period of time the minimum length of which is measured by the peneplanation of the Unkar-Chuar mountains, Arizona, which were two miles in height, and of other late Proterozoic dislocations. This period was given the name "Laurentide revolution" by Le Conte.[112] He states:

> "The first and by far the greatest of these lost intervals is that which occurs between the Archæan and the Paleozoic. In every part of the earth where the contact has been yet observed the Primordial [= Cambric] lies unconformably on the upturned and eroded edges of the Archæan strata. . . . As upturned eroded outcropping strata mean land-surface, it is evident that there was at that time *a very large area, or else several large areas of land,* in the place now occupied by the American continent. . . . It was *a continental Period.* . . . Was *land of the Lost Interval.*"

*Georgic period or system.**—The Laurentide emergent period closed the Proterozoic era and the Paleozoic began with the "Georgian" series. Walcott (1891) demonstrated the existence of a long trough (see plate 51) that at this time extended from Alabama northeast to Labrador, being situated on the inner sides of Acadia and Appalachia. In the west the Cordilleran sea also appeared on the inner side of Cascadia, but in the earlier transgressive stages did not connect the Pacific with the Arctic ocean. While no secular changes of this time are known in the lands bounding these seas, yet from their very position and character it might be asserted that during the close of the Proterozoic Acadia, Appalachia, and Cascadia had been thrust away from the oceans, developing synclinal seas along their inner sides. It was these synclines that the transgressive seas invaded. These bordering lands were then still high, and in the earlier stages furnished much clastic material in formations of great thickness. The lands of the interior, however, appear to have been low and featureless. The synclinal seas were the beginnings of the Saint Lawrence, Appalachian, and Cordilleran transgressive seas.

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[112] Le Conte: American Journal of Science, vol. 14, 1877, p. 101.

* Lower Cambrian and Georgian of most writers.

The maximum inundation of the North American continent apparently did not exceed 18 per cent, and that of the United States 12 per cent.[113] This inundation was also slow in spreading, first appearing in the Great Basin and gradually moving northward. In the east the Appalachian sea may have first shown itself in the northern Appalachian trough, from Pennsylvania to northern Vermont and thence northeast to Labrador and south to Alabama.

Toward the close of the Georgic the eastern lands are known to have moved, and apparently this elevation drained the entire trough from Labrador to Alabama. This movement is of great significance in the subsequent distribution of the faunas, for it is seen that when the seas again invaded the region of this fold the descendants of the former universal Pacific Olenellus faunas were prevented from mixing with those of the northern Atlantic. On the west of this protaxis of "Middle Cambric" time were the Olenoides faunas of the Pacific realm, while to the east are the Atlantic Paradoxides biotas. Here occurred, therefore, the birth of the Appalachian protaxis of Dana and the Chilhowee-Green Mountain barrier of Ulrich and Schuchert.[114] In the Cordilleran region the seas are continuous.

Acadic period or system[115]—Saint Croix transgression (see map, plate 52).—Following upon this eastern movement a great transgression was introduced with fair rapidity, one of the Pacific ocean from the previously synclinal Cordilleran sea. It was a very shallow continental sea—"a sea which just bathed its [continental] surface."[116] It washed together the sandy regolith and spread east to Appalachia and north around Wisconsia island. According to the paleogeographic map, plate 52, about 31 per cent of the North American continent was submerged and about 46 per cent of the United States. This is the Saint Croix invasion of Ulrich and Schuchert (1902, 636), marking "an important event in the development of the present continent, this being nothing less than the birth of the great interior continental sea, to which Walcott has applied the term "Mississippian sea." The duration of this transgression embraced all the Middle Cambric and some of the Upper Cambric as generally defined. Then, without apparent elevation of the North American continent, a more rapid negative movement of the strand-line began, which may be called the

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[113] The estimates given in this chapter are exact calculations based on the writer's paleogeographic maps. It must be understood, however, that in all probability the maps are not accurate and can not be made so for years to come. The figures given, therefore, are but expressions of present knowledge, yet are believed to represent the relative amount of inundations and emergences. The area here called "United States" embraces more than this country—all the present land between 30° and 50° north latitude. Geologically, it is the best-known region.

[114] Ulrich and Schuchert: Rep. New York State Paleontologist, 1902, p. 638.

[115] Middle Cambrian and Acadian of most writers.

Franconia emergence (not mapped).—This emergence began in the north with the Franconia sandstone of the Saint Croix series.[117] According to Ulrich, the emerging deposits are nearly everywhere marked by an "edgewise conglomerate" and a noticeable sprinkling of glauconite. He observed these features "in association with a no less characteristic fauna in central Texas, western Texas, in the Arbuckle and Wichita mountains of Oklahoma, at several points in the Appalachian valley, in southeast Missouri, at Lansing, Iowa, the Black Hills, and the Big Horn mountains." It is probable that more than one-half of the area of the previous transgression emerged during this period.

Ozarkic period or system[118]—Ozarkian transgression (see map, plate 53).—Without known secular movements of an adequate character this transgression spread throughout the Mississippian sea somewhat less widely but more slowly than the Saint Croix transgression. It continued northeastward, surrounded Adirondackia, and to a limited extent occupied the Saint Lawrence trough, while the Cordilleran sea was restricted to the more immediate region of its syncline. According to the paleogeographic map of this time, about 21 per cent of North America was submerged and about 28 per cent of the United States. This transgression was therefore about 10 per cent and 18 per cent respectively smaller than the previous one and of about the same extent as the one following.

In the Mississippian sea the deposits were mostly magnesian limestones, always of great thickness, in the Arbuckle mountains of Oklahoma reaching at least 4,000 feet in depth. Again the waters quietly withdrew, and as the maximum emergence succeeded the Shakopee dolomite this fixed the name for the

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[116] Dana: American Journal of Science, vol. 22, 1856, p. 339.

[117] Berkey: American Geologist, vol. 20, 1897, pp. 372-377.

[118] Mainly Upper Cambrian of writers and in part the base of their Ordovician.

Shakopee emergence (see map, plate 53).—The area of this emergence was of considerable extent and the waters were drawn away to the south. According to the paleogeographic map, about 12 per cent of North America remained under the sea and about 26 per cent of the United States. This emergence was seemingly not of long duration, for a secular movement was again recorded in Acadia and Appalachia. The Green Mountain-Chilhowee axis in the north and south became a definite barrier for the separation of most subsequent Ordovicic waters. While this secular change locally affected the seaways in Acadia and accentuated the synclinal seas, yet it could not have been the cause for the next important alteration in the strand-line. The introduction of this positive movement closed the Ozarkic period and began the

Canadic period or system[119]—Beekmantown transgression (see map, plate 54).—This invasion had the character of a transgressive sea, but was not nearly so positive as that of the Saint Croix, being about that of the Ozarkian. For the continent the figure was about 23 per cent, and for the United States about 30 per cent. The Sonoran sea, with its Pacific faunas, flowed around south Missouria and widely west of Appalachia, continuing with its characteristic life out through the north Saint Lawrence trough, or more properly the Chazy trough, its blended faunas occurring in Newfoundland. Throughout it was a sea forming dolomite-limestone, the deposits attaining a thickness of 2,500 feet in the Mississippian sea. On the other side of the Green Mountain axis, however, in the Levis trough, occur clastic rocks with different faunas, best compared with those of Scotland and Sweden. These were derived from the Saint Lawrence sea, which at this time appears to have had no connection with the Chazy trough, being clearly of another faunal realm. As is shown elsewhere by Ulrich, the Beekmantown sea was oscillatory, and for a long time the invasion was fairly persistent. Without definite cause, apparently, the strand-line again became negative, and there resulted the

Saint Peter emergence (see map, plate 55).—According to the map, this emergence left but 12 per cent of the North American continent submerged and 22 per cent of the United States. It is probable, however, that the waters were withdrawn even more than is represented by these figures, for there is a hiatus in the deposits of nearly all the known outcrops. The emergence appears to have been of short duration, and the faunas marking it are best known in Missouri and Arkansas. The weathered sands of the Saint Croix deposits composed the regolith in the

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[119] Lower Ordovician or Canadian of American stratigraphers.

Mississippi valley and furnished the well assorted material of the basal deposits of the next submergence.

Ordovicic period or system[120]—Trenton transgression (see maps, plates 56-59).—This positive but markedly oscillatory movement of the strandline was at first slow in its expansion, but the Stones River area of the southeastern Mississippian sea gradually moved along Appalachia, continuing through the Champlain trough into the Chazy trough certainly as far northeast as Mingan and probably across Newfoundland. This record may be seen in the Chazy limestone, but it was only during the latter part of Chazy time that the interior sea was continuous with that of the Champlain-Chazy trough. Ulrich shows that the sea was decidedly oscillatory during the Holston, Lowville, and Black River stages of this transgression, and finally, early in the Trenton, the flood became general throughout the North American continent. The waters on the four sides of the continent contributed their faunas, the transgression being the greatest of all those known in North America. It is the Black River transgression of Ulrich and Schuchert (1902, 641). The amount of inundation was as follows:

	North America.	United States.
Middle Stones River and Chazy..................	26 per cent	29 per cent
Lowville	30 " "	38 " "
Lowest Trenton	57 " "	61 " "

The flood came from the Arctic region, and for the first time since the Proterozoic all the central flat land of northern North America was inundated. It was clearly a movement of the hydrosphere, since all subsequent Paleozoic formations of the Hudson bay and adjoining regions to the west now rest concordantly upon one another, indicating that no appreciable warping of the land was caused by this transgression and the later Paleozoic emergences and submergences.

In the Saint Lawrence trough this submergence also became general, and at various times the Green Mountain barrier was transgressed, so that the Atlantic faunas had rather free access to the Mississippian sea. In early Trenton times the inundation remained at its maximum, but throughout the later Trenton emergence was again in progress.

Utica emergence (see map, plate 60).—As in all emergences, the waters connected with this one subsided far more rapidly than they advanced. The Trenton transgression disappeared quickly in the north, more slowly in the west and south, so that finally in the northeast there was left a sea of considerable extent—the early Utica sea—depositing mainly black shales and entombing an Atlantic nektonic-pelagic fauna quite foreign to the Mississippian sea. In the early stages the Utica sea covered about 10 per cent of North America, then gradually became smaller, and during the later portion of this time the tide turned, the strand-line slowly becoming positive and bringing back the normal faunas for the Mississippian sea, in this case the Eden and Lorraine.

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[120] Middle Ordovician of American stratigraphers.

Cincinnatic period[121]—Richmond transgression (plates 61, 62).—During Lorraine or Maysville time the strand was not very positive, as the sea was withdrawn more and more from New York. In the southwestern part of Ohio the latest Utica and Eden were continuous into the Lorraine, but at this time communication was again established with the southern Appalachian trough, thus introducing the Gulf faunas. In the Cincinnati region the Lorraine passed not quite uninterruptedly into the Arnheim stage of the Lower Richmond, the sea being then probably more to the east along the deeper water off the axis. Slowly the Taconic revolution dissipated the Mississippian sea to the northeast of the Cincinnati axis, and finally in the later Richmond the inundation again became general west of the axis, almost duplicating the Trenton transgression. The figures are as follows:

	North America.	United States.
Trenton transgression	57 per cent	61 per cent
Richmond "	40 " "	44 " "

The Utica emergence left the North American continent with its previous attitude, so that the Richmond transgression laid down its deposits in perfect concordance with the older formations. This sea was also an oscillatory one, the pulsations being best recorded in the Mississippi valley. It will be some years, however, before Ulrich can describe the various faunules which together make up the Richmond series. On Anticosti the connecting record is complete, and its interpretation is now being attempted at Yale University; hence it is hoped that the line which separates the Cincinnatic from the Siluric may soon be located. The Richmond faunas have northern European affiliations, but because of the nearly universal and broadly intercommunicating continental seas it is expected that southern Poseidon, Pacific, and Arctic elements will sooner or later come to light.

The Richmond transgression was closed by the Taconic revolution, during which time there was great subsidence of the seas. The final waters were local in situation, being possibly of the nature of attracted seas, and their faunas more and more assumed a Siluric aspect.

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[121] Cincinnatian or Upper Ordovician of geologists.

Taconic revolution.—The period of this secular unrest was of long duration, clearly beginning with the Trenton emergence and persisting to the close of the Cincinnatic. The North Atlantic ocean was subsiding, and as a result of this movement the older Paleozoic strata of eastern America and western Europe were finally, by the tangential thrusts of the Atlantic, thrown into folds upon which the succeeding deposits of these areas rest discordantly.[122] The movement was at first gentle, but culminated in the widespread Richmond transgression, and at its completion showed a new arrangement of lands and seas due to the decided secular changes previous to the Siluric. The first noticeable effect of this developing revolution may be seen in the turbulence of the oscillatory seas of Mohawkian time, as described by Ulrich, and in the birth of the Cincinnati axis or parma, never a marked feature of the Mississippian sea until the Siluric. The axis at first appeared at the south as an island—Nashvillia—as early as the Lowville, and persisted into earliest Trenton time. Subsequently it was submerged, but reappeared in the Lorraine, and was greatly enlarged during the Richmond. In the north its record is rather one of submergence, but with the subsidence of the Richmond transgression the Cincinnati axis was ever afterwards a distinctive feature of the Mississippian sea. With the rise of this low fold two other parmas appeared, having similar trends, the eastern one being Alleghania and the western one Kankakeia. The former apparently began with the Utica emergence, but was more certainly visible in the Richmond transgression, while Kankakeia was not clearly seen as an axis until the Niagaran transgression of the Siluric. The Pacific ocean also subsided, but its lateral effect was not so continued and violent as that of the Atlantic, as no upturnings are here known. However, somewhat later, when the Niagaran transgression was at its maximum, it is evident that the Cordilleran and Mississippian seas no longer had the free and wide open intercommunication of earlier periods, but that in great part they were now separated by the extensive land Siouxia, which was but the northern part of Columbia.

The Taconic revolution of the North Atlantic is of great significance in stratigraphy and paleontology, since in eastern North America the upturnings, according to Dana,[123] "extend all the way from the Saint Lawrence valley to New York city, . . . through Virginia southwestward, along a series of Taconic geosynclines that ended in the making of a series of Taconic ranges." With the exception of the Appalachian revolution which closes the Paleozoic, this secular disturbance was the most marked one of the era, withdrawing as it did the water from the North American continent to such an extent that finally all retreated except that in the immediate Mississippi valley. Here several pulsations of the sea have left a record of small faunas. In the outer portions of the Saint Lawrence trough, however, the attracted sea continued throughout the time of the Taconic revolution, and on the island Anticosti there is a good fossiliferous record of this entire interval preserved in over 1,700 feet of thin-bedded limestones and shales. This record begins early in the Richmond, and continues unbroken into the Rochester of the Siluric, the entire section having a thickness of more than 2,300 feet. In the entire depth of these deposits there are but two thick shale zones, one in the Upper Richmond, the other just before Clinton time. That this shallow bay felt the unrest of the closing stages of the "Ordovicic" is proved by the sections described by Richardson.[124] Throughout Divisions A and B, which have a combined thickness of 959 feet, are innumerable zones of intraformational conglomerates. This is the time of the Richmond of the Mississippian sea. The fauna of the Richmond then continues through Division C, having a thickness of 306 feet, where more conglomerates were seen. Division D represents about the time of the Ohio Clinton of the Siluric, when the Niagaran invasion takes on a more decided aspect.

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[122] There is also at about this time marked movement in western Sonora, Mexico, as nere the uppermost El Paso limestone (= Richmondian) rests discordantly upon other limestones supposed to be of Beekmantown age. The Richmond fossils have been collected by E. T. Dumble and sent to the writer. The structure of the region is described by the former in Transactions of the American Institute of Mining Engineers, vol. 29, 1900.

[123] Dana: Manual of Geology, 1895, pp. 387, 531.

Siluric period or system—Niagaran transgression (see maps, plates 63-68).—The Taconic revolution ended in an almost complete emergence of the North American continent; in fact, the continent was at that time nearly as large as at the close of the Proterozoic. The only area remaining submerged was the outer portion of the Saint Lawrence sea, this being represented by a bay, an attracted arm of the ocean, extending from southwest of Anticosti across northern Newfoundland. In the immediate region of the Mississippi river, as far north as northern Illinois, the sea appears to have been erratic, and the record is not only incomplete but the deposits are very thin, the best representation being in the Edgewood beds. This horizon is also thought to indicate the time of the topmost Medina, the zone with the marine fauna described by Hall in 1852. The Medina deposits are of a synclinal sea occupying restricted areas of the Appalachian sea. These were followed by the beginnings of the Niagaran transgression first seen in the Ohio-Clinton deposits. In the later Clinton the more widespread inundation was continued, and attained its climax about Louisville time. The waters abounded in life, especially corals. This transgression was described by Ulrich and Schuchert as the Oswegan invasion (1902, 647), for which the preferable name Niagaran transgression is here substituted. The amount of inundation is shown by the following figures:

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[124] Richardson: Report of Progress, Geological Survey of Canada, 1857, pp. 191-238.

	North America.	United States.
Medina-Edgewood	5 per cent	9 per cent
Early or Ohio-Clinton	5 " "	11 " "
Middle Clinton	14 " "	14 " "
Rochester-Osgood	34 " "	29 " "
Louisville	35 " "	35 " "

The deposits of the Appalachian sea are mainly clastic, being derived from rejuvenated Appalachia. West of the Cincinnati axis, however, most of the material is organic in nature, being chiefly limestone in the Oklahoma and Indiana basins, while in the Ohio and Iowa basins, under the dominant influence of the very shallow Hudson sea, the deposits are dolomites.

An examination of the maps showing the variations in this transgression in eastern America will draw attention to the fact that the invasion was at first controlled by slight movements of Appalachia, for the seas lay on its inner side in the renewed syncline and on each side of the Cincinnati axis, which also has the strike of the eastern land. In other words, the inward movement of Appalachia accentuated not only the synclines occupied by the continental seas, but likewise affected the parmas Alleghania, Cincinnatia, and Kankakeia. Finally, between the thrusts of the Atlantic and the Pacific was produced the low land Siouxia, the barrier preventing the intermigration of the faunas of these two realms. The original nucleus of the North American continent, however, was not influenced by the oceanic subsidences, but remained as an unmoved continental horst. Only the Arctic waters again became widespread on its western side. However, the writer has no intention of conveying the idea that these parmas and the land Siouxia were directly and wholly bowed up by the tangential thrusts of the Atlantic and Pacific. It is probable that the tangential forces were the primary cause of this action, but that during these movements isostatic compensation was the direct force in bringing about these flexures through vertical movements immediately below the arches.

That in Acadia the greater part of the submergence was marked by extensive volcanic activity is proved by the statement made by members of the Federal Survey to the writer, showing that in southeastern Maine not less than 46,000 feet of material were deposited during this interval, by far the smaller amount of which was of clastic marine origin.

Cayugan emergence (U. and S., 1902, 648) (plates 69-71).—Without apparent cause, as far as the North American continent is concerned, an emergence began with the Guelph. As usual, the withdrawal of the sea was again fairly rapid. With the Guelph the great northern or Hudson sea vanished, and possibly even earlier all the Indiana basin had disappeared. For a long time the known oceanic extensions were then confined to the northeastern part of the United States in the northern Appalachian, Ohio, and northern Indiana basins, and farther northeast in the Saint Lawrence sea of the Acadian region. According to the maps, the emergence is represented by the following figures:

	North America.	United States.
Guelph	31 per cent	20 per cent
Lower Salina	6 " "	10 " "
Bertie	5 " "	10 " "
Lower Manlius	5 " "	10 " "

In the United States, after the Guelph, these seas were very shallow—not normal marine waters. The sedimentary record is one either of red shales with salt and gypsum, or thin dolomites or water-limestones. The seas were those of an arid climate, with salt pans and shallow stretches alternately exposed to the effects of the sun, as demonstrated by the sun-cracked "ribbon limestones" or calcareous shales to be seen in many widely separated places. At last the greater part of these waters subsided, and the Siluric ended with an emergence that was nearly as extensive as the one at the beginning of this period. Suess also points out this emergence by stating: "The Silurian concludes in England, as in North America, with an unmistakable and considerable diminution in the depth of the sea" (II: 225).

Devonic period or system—Onondaga transgression (Ulrich and Schuchert, 1902, 652. See maps, plates 72-76).—The widespread emergence at the close of the Siluric continued into the Devonic, and for a time, which may be measured by the Helderbergian and Oriskanian deposits, the sea was oscillatory. This movement did not become decidedly positive until toward the close of the Oriskanian. In the east the seas of this interval appear to have been of the synclinal type, while those of the Mexico embayment represented the early stages of the transgressive sea. Late in the Oriskany the flood began to spread westward through New York, and very early in Onondaga time the sea became general along the western side of the Cincinnati axis. Through the Mexico embayment the warm waters of the Gulf of Mexico spread, and reached even as far as James bay. This sea brought in the well known coral fauna, best represented in the region of Louisville, Kentucky. At the same time the northern Atlantic extended across northern Appalachia and brought with it the Schoharie fauna, rich in cephalopods. The Saint Lawrence embayments had been continuous from the earliest Devonic, and across the Taconic uplift, in free communication with the Lower Devonic seas of the northern Appalachian region. This intercommunication persisted into the Onondaga, when decided secular changes took place in Acadia, which practically barred further marine access to the Saint Lawrence waterways until Mississippic time. This elevation is also recorded in Appalachia, but earlier, as the siliceous materials of the Oriskany and Camden are clearly of this land. The rejuvenation of Appalachia which began in the Oriskany dissipated the southern portion of this sea, and the elevation became more decided in Onondaga time, its deposits being absent throughout the Appalachian area from central Pennsylvania southward. During the later Devonic Appalachia continued to be elevated, more and more of the southern Appalachian sea and the Mexico embayment being obliterated.

The flood reached its maximum in the late Hamilton, and then another great northern sea appeared—the Cordilleran sea, with its Euro-Asiatic faunas, extending from the Arctic ocean to Iowa and from Montana to northern Nevada. For a time the Kankakee axis separated this western sea from the Mississippian sea, but at the close of the Hamilton the waters spread across this narrow barrier, and to a limited extent the faunas of the two areas mixed. This condition is best seen in the Devonic biotas occurring about Milwaukee, Wisconsin.

According to the maps, the transgression progressed as follows:

	North America.	United States.
New Scotland	6 per cent	13 per cent
Becraft	6 " "	11 " "
Decewville	8 " "	13 " "
Middle Onondaga	16 " "	19 " "
Late Hamilton	35 " "	32 " "

This great transgression was first pointed out by Suess. He states:

> "A very considerable extension of the Devonian seas took place simultaneously from the Ural over the Russian plain toward the west and northwest, and from the Rocky mountains across the valley of the Mackenzie to the east. . . . The positive phase in the middle of the Devonian system thus manifests itself on both sides of the Atlantic ocean at the same time" (II: 232, 233).

Chemung emergence (see map, plate 77).—The Middle Devonic transgression just described continued unbroken in the Cordilleran sea and invaded further areas in the southwest; along the Atlantic, however, there was marked unrest. As has been seen, Appalachia was in movement early in the Oriskany, as shown by the absence of Upper Oriskany and Onondaga deposits in the southern Appalachian sea. In Marcellus time the northern area of this same sea again began to spread southward, reaching southern Kentucky, and then extending across the Cincinnati axis into the Indiana basin. South of Kentucky the Appalachian trough was land, and thus remained throughout the Upper Devonic. This uplift does not appear to have been a marked one, however, certainly not for the southern half of Appalachia, for the clastic material of the adjoining seas, which were of late Devonic and early Mississippic times, consists of black shales of a very fine texture. During the Middle Devonic, Acadia was repeatedly subjected to tangential movement, and this area has furnished the major amount of the vast clastic material of the late, Middle, and Upper Devonic formations of the northern Appalachian trough. Nevertheless, throughout the period of these secular movements the Atlantic at different times crossed northern Appalachia and distributed its faunas in the New York basin.

It is evident, therefore, that the Chemung emergence was more specifically a condition of the Atlantic border, and that it became even more marked in the Mississippic period. It of course decidedly affected the areal distribution of the Appalachian, Saint Lawrence, and Mississippian seas, but the Cordilleran and Sonoran seas continued with but little physical change into the succeeding period. As the Cordilleran and Mississippian seas may have remained in continuous communication from the late Hamilton, the faunas of the latter sea have much the same aspect as those of the former throughout Upper Devonic time. In the early Mississippic the Kankakee axis was somewhat accentuated, and for a time kept the Cordilleran and Mississippian seas apart. It was this barrier, together with the changes in Acadia and Appalachia, and some withdrawal of the continental waters, that caused the more decided faunal changes in the eastern seas. In the western or Cordilleran sea, however, there was a less decided faunal change at the close of the Devonic. In other words, the diastrophism at the conclusion of the Devonic does not appear to have been marked in character, as the emergence recorded in the map (plate 77) was but 2 per cent smaller than that of the late Hamilton. But a greater emergence took place at the very close of the Devonic, and may have decreased the area of the Middle Devonic by from 9 to 15 per cent; this difference, however, was sufficient to change the faunas. In this instance the life record is thought to have greater value than the physical one in separating the Devonic from the Mississippic, but should the principle of diastrophism be the sole guide, then these two periods seemingly must be combined into one.

Mississippic period or system (emend)[125]—Fern Glen invasion (see maps, plates 78-80).—It has been seen that the Chemung emergence that closed the Devonic was not so decided as those of the earlier periods. For this reason the Mississippic invasion was more extensive in its early stages, yet the physical changes during the Chemung emergence were of sufficient importance to cause the localization of the faunas and their rather marked variation. There were five of these faunas. The northern Appalachian sea had the Bradfordian faunas of Chemung aspect, together with migrants from the Atlantic, but this basin was not at all in connection with the other continental seas. The restricted Mississippian sea was a new invasion and in open connection with the Gulf of Mexico, a region having faunas that are more in harmony with those of Europe than any other. On the other hand, the Cordilleran sea was still of wide extent, and was characterized by the Madison faunas. The eastern expansion of this sea in the Iowa and Oklahoma basins has another impress in the Glen Park faunas, for the Madison elements are here blended with those held over from the Hamilton and of Gulf of Mexico origin. In the Saint Lawrence sea there appear to have been no deposits of earliest Mississippic time, the later faunas here represented being again different, and very unlike those of Europe. It is in the eastern seas with Atlantic connections that the earliest appearance of *Syringothyris* is met with, and this genus of brachiopods is the accepted criterion for Mississippic time. The basis for the beginning of Mississippic time is therefore faunal, though a slight diastrophic movement contributes to the same end.

The Fern Glen transgression attained greater area late in the Kinderhook, when there was again established more or less free communication between the various seas. Further inundation occurred when nearly all the areas again deposited limestones, and the climax was attained in late Burlington and early Keokuk time, the period of wonderful crinoid development. An emergence then set in which may be called the

Keokuk emergence.—Within the "Warsaw formation" above the Keokuk there is a hiatus of wide extent. The lower portion, according to Weller, is the true Warsaw, while the upper part belongs to the Spergen. Not only were the waters greatly withdrawn during the Keokuk emergence from the Mississippian and Appalachian seas, but the entire Cordilleran sea appears to have vanished. This western emergence in the northern region appears to represent permanent addition of land to Laurentia, for when the Pacific again invaded western America the invasion is seen to be marginal and Cascadia was greatly reduced in extent. In the Mississippian sea the emergence was due to withdrawal of the waters without apparent land movement. This emergence apparently resulted from subsidence in the Pacific realm. The next invasion was a small one, and as it had well marked faunas, combined with peculiar physical characters, it is here distinguished under a new systemic term.

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[125] The lower half only of the Mississippian of stratigraphers.

Tennesseic period or system[126]—Saint Louis invasion (see maps, plates 81, 82).—The Upper Warsaw, a part of the Spergen, of restricted extent, began another invasion that attained its climax in the Saint Louis. This was the smallest inundation of the Paleozoic, and was chiefly confined to the Mississippian and Appalachian seas. There was no Cordilleran sea of this time. The material deposited by these waters in connection with the subsequent emergence—the *Kaskaskia emergence*—attained a minimum thickness of about 1,100 feet, with a maximum of 1,800 feet. The beds are repeatedly marked by zones of oolite containing a characteristic dwarf fauna known as the Spergen fauna. The invasion is distinguished by limestones and oolites, while in the emergence the oolites occur between sandstones. The sea ended in deposits of limestone, oolites, and shales.

This small invasion was in harmony with the general and almost continuously progressive emergence beginning in the Chemung and terminating with the Tennesseic. However, on the long enduring Onondaga transgression were superimposed two smaller accentuated emergences having, it is thought, each the value of a system or period. Finally the entire continent was emergent except a limited area in the Oklahoma basin, which was continuous into Pennsylvanic time. To make these statements more clear, the percentages of marine invasions from the maximum in the Hamilton to the end of the Tennesseic are here given, as follows:

	North America.	United States.
Late Hamilton	35 per cent	32 per cent
Ithaca-Chemung	33 " "	33 " "
Close of Devonic, estimated	20 " "	23 " "
Bradfordian	24 " "	30 " "
Fern Glen	25 " "	36 " "
Burlington	20 " "	24 " "
Close of Keokuk, estimated	5 " "	8 " "
Saint Louis	7 " "	10 " "
Chester	13 " "	12 " "
Close of Chester, estimated	7 " "	8 " "

Throughout the close of the Tennesseic, Appalachia must have been in constant elevation, especially in the southern portion, for very thick deposits of coarse material that are mainly continental in character are seen in the Appalachian trough of early Pennsylvanic time. Later in the same period this emergence was greatly accentuated, and forever obliterated the Mississippian sea.

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[126] The upper half of the Mississippian of stratigraphers and Tennessean of Ulrich.

Pennsylvanic-Permic period or system.—Pottsville transgression (see map, plate 83).—This was a transgression of the Gulf of Mexico and the southern Pacific as seen in the widespread Cordilleran, Sonoran, and Mississippian seas. It also affected, but less persistently, the Appalachian sea. The eastern distinctly aggrading seas, however, were so near sealevel that they often became brackish and fresh-water marshes, which was particularly true of the Appalachian area. Loading went on, and every now and then the continental region subsided sufficiently to permit an extensive areal invasion of marine waters, but the rivers constantly pushed their loads farther and farther seaward, so that there resulted an alternation of continental deposits interspersed with limited marine zones. The latter are rarely met with in the southern and extreme northern Appalachian areas, more often in the medial Appalachian region, while in the eastern, but more especially in the western, portion of the Mississippian sea the marine deposits are more frequently dominant. Worthen[127] gives a composite section of the "Upper Coal Measures" of northern Illinois adjoining the upper course of the Kaskaskia and Wabash rivers, in which there are 95 zones having a united thickness varying from 1,072 to 1,722 feet. In these deposits there are 19 fossiliferous marine zones alternating with 17 coal beds. The latter vary in depth from 6 inches to 9 feet, averaging about 2 feet and 6 inches, while the marine zones of shale or limestone vary from 1 foot to 25 feet, averaging 6 feet in thickness. The intermediate zones are shale and sandstone.

In late Pennsylvanic time normal marine conditions again prevailed in the western areas of the Mississippian sea, and finally in the north this region also passed into coal-marsh conditions, while in the south the retreating sea of early Permic time deposited red shales and vast quantities of gypsum. In the Cordilleran sea the conditions throughout were those of a normal marine sea.

The alternation of marine and continental deposits is particularly characteristic of the Pennsylvanic in nearly all lands of the northern hemisphere, from England to Moravia, Carinthia, probably in Spain, northern China, and the United States (see Suess, II: 243).

The Pennsylvanic was a time "of extraordinary duration. . . . In the middle of the Coal-measure period [of Europe] a number of great folded ranges were both elevated and worn down by denudation, and the younger measures passed in transgression over the abraded surfaces of the folds into which the earlier measures had been thrown" (Suess, II: 248, 249).

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[127] Worthen: Geological Survey of Illinois, vol. 6, 1875, pp. 2-5.

Appalachian revolution (see maps, plates 84, 85).—Beginning in the early Devonic, North America underwent one great transgression of long duration which culminated late in the Hamilton, and was followed by what may be called an uncertain emergence of long continuance. This emergence was marked by two minor and one major transgressions—the Fern Glen, Saint Louis, and Pottsville. During this vast period of time enormous quantities of material had been transferred from the lands into the subsiding continental seas, filling them beyond the limit of their capacity. The neighboring lands were again mainly featureless, and a long period ensued in which the eastern half of the United States was a vast region of aggrading marshes producing luxuriant floras not much unlike those of Europe. The loading areas spasmodically and irregularly subsided, for short intervals letting in the marine waters, but these always yielded the same fauna of enduring hardy species. The seas were slowly but haltingly withdrawn. This is the history of nearly all late Paleozoic continental seas. It is therefore concluded that not only were the oceanic basins subsiding, but at irregular intervals the continental loading areas as well, and thus was developed an oscillatory negative strand-line.

The concluding Paleozoic withdrawal of the seas began early in the Pottsville in the southern Appalachian sea, later in the northern area of this same trough, and finally throughout the northeastern portion of the Mississippian sea. This was about the time of the latest Pennsylvanic, but to the north, west, and southwest of Missouria the sea remained for a short interval; then during the early Permic the waters gradually passed away southward, leaving red clays and vast quantities of gypsum in their wake. The Sonoran and Californian seas retreated less slowly, and in the later Permic the only continental sea remaining was the restricted Sonoran sea of Guadalupian time. Even it finally vanished, and the American Paleozoic sedimentary record is at an end. According to the maps, the percentages of marine inundations are as follows:

	North America.	United States.
Upper Pottsville	27 per cent	36 per cent
Upper Pennsylvanic	18 " "	31 " "
Lower Permic	3 " "	25 " "
Late Permic	1 " "	1 " "

This gives the history of slowly but constantly subsiding oceanic areas, with the withdrawal of the continental waters. Through this subsidence the border region of eastern North America was once more thrown into a series of folds greater than any others of Paleozoic time, extending from Oklahoma to Newfoundland and probably beyond. Along the Pacific border the compression appears to have been slight. The continent was again as large as at the beginning of the Paleozoic era, and thus it remained nearly to the close of the Triassic, when the Pacific began to overlap the border. Along the Atlantic the continent remained emergent until the latter half of the Cretacic. The slow production of cumulative stresses is therefore seen until the breaking period was reached late in Pennsylvanic time, the unrest lasting until the end of the Permic. This was the condition of the northern Atlantic or Poseidon ocean. Of those established on fossil evidence, it represents the most critical period in the history of the earth.

This slow retreat of the late Paleozoic seas and the final quiet death in old age of the Mississippian sea furnish the cause for the difficulty experienced by American paleontologists in delimiting the Pennsylvanic and Permic systems. The guiding faunas and the diastrophic record must come from other and more equatorial lands, as these are more sensitive to the pulsations of the late Paleozoic normal seas. This record is now fairly well ascertained in the lands bordering the Mediterranean, which in late Paleozoic time was at the bottom of the greater Tethys,[128] extending from Spain to the Pacific and Indian oceans.

SUMMARY OF EMERGENCES AND TRANSGRESSIONS

Explanation of the table.—The appended table is a digest of the foregoing descriptions of Paleozoic emergences and transgressions, to which has been added the more important information of a similar character concerning subsequent periods. The names of these periods or parts of periods are given in the first column.

The second column gives in percentages the amount of submergence in the North American continent at the times specified, and also in the area between 30° and 50° north latitude. The latter area will be referred to as the United States. According to the base used in plotting the paleogeography, the North American continent, including Mexico, has about 8,200,000 square miles, the area of the United States representing about 3,530,000 square miles.

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[128] "Now let us quit the coasts and examine the interior of a great continent.

"Modern geology permits us to follow the first outlines of the history of a great ocean which once stretched across parts of Eurasia. The folded and crumpled deposits of this ocean stand forth to heaven in Thibet, Himalaya, and the Alps. This ocean we designate by the name 'Tethys,' after the sister and consort of Oceanus. The latest successor of the Tethyan Sea is the present Mediterranean." Suess: "Are ocean depths permanent?" Natural Science, vol. 2, 1893, p. 183.

Table of North American Emergences and Submergences

Name.	Maximum and minimum of areas in North America and the United States.		Regional movements.	Seas present.	Direction of flow of water—in or out.	Rate of change of strand-line.
Georgic transgression and emergence.	17.6	12.0	Marked At.	C., Ap., L., At., G.	+ P. and At.	Slow.
Saint Croix transgression	31.6	46.7	None	C., S., M., Ap., G., L.	Extensive P. and G. + Slight At.	Fairly rapid.
Franconia emergence	(?) 15.0	(?) 25.0	None	C., M., Ap., G., L.	— Mainly P. and G.	Rapid. Stay short.
Ozarkian transgression	21.7	28.9	None	M., Ap., C., G., L.	+ Mainly G. and C.	Slow.
Shakopee emergence	12.2	26.0	Marked At.	M., Ap., G.	— G.	Rapid. Stay short.
Beekmantown transgression	22.7	30.3	None.	C., S., M., Ap., L., G.	+ P., At.	Slow.
Saint Peter emergence	12.7	22.0	None	S., C., M., Ap., G.	— P., At.	Rapid. Stay short.
Trenton transgression	57.2	61.2	None	H., C., M., S., Ap., L., G.	+ Ar., P., At.	Slow.
Utica emergence	10.0	10.0	Slight At.	Ap., L., G.	— Ar., P.	Fairly rapid. Stay short.
Richmond transgression	40.0	44.3	None	H., C., M., S., Ap., L., G.	+ Ar., P., At.	Rapid.
Taconic revolution	0.0	0.0	Decided At.	G., L.	— Ar., P., At.	Slow. Stay long.
Niagaran transgression	35.9	35.7	Slight in northern At	H., C., M., Ap., L., G.	+ Ar., G., C., At.	Very slow.
Cayugan emergence	5.3	10.9	None	Ap., L., G., C.	— Ar., P., G., At.	Rapid. Stay long.
Onondaga transgression	35.2	32.0	Marked At.	M., C., Ap., G., S., L.	+ G., Ar., P., At.	Invasion slow.
Chemung emergence	33.0	33.0	Marked At.	C., M., S., Ap.	— P., Ar., At.	Slow.
Fern Glen transgression	25.1	36.1	Slight At.	C., S., M., G., Ap., L.	+ P., Ar., G., At	Slowly emergent.
Keokuk emergence	20.1	24.8	None	C., M., G., L., Ap.	— P., G.	Rapid. Stay very short.
Saint Louis transgression	7.6	10.0	None	M., G., Ap., L.	+ G.	Slowly emergent.
Kaskaskia emergence	13.4	12.1	Marked At. G.	M., G., Ap.	— G.	Slowly emergent. Stay short.
Pottsville transgression	27.7	36.4	None	C., S., M., Ap., G., L.	+ P., G.	Rapid.
Appalachian revolution	3.3	25.1	Very decided At.	C., S., M., G., Ap., L.	— P., G.	Slow. Stay very long.
Permic	1.6	1.1	(?) Decided At.	C., S., M., G.	— P., G.	Highly emergent.
Triassic	1.7 15.4	4.0 8.4	None.	P., Ar.	∓ P.	Highly emergent.
Jurassic	3.7 13.8	7.3 18.4	Decided P. Slight At.	P., G.	∓ P., G.	Highly emergent.
Comanchic	7.9 19.0	8.2 13.6	Locally P. Decided G.	G., P., Ar.	∓ G., P.	In slow. Out rapid.
Cretacic	30.4 1.8	42.1 2.1	Very decided entire P. Also some At.	G., Ar., P., At.	∓ G., Ar., P., At.	In rapid. Out slow.
Eocene	4.9	11.4	Slight P.	G., At., P.	G., At., P.	Highly emergent, except Gulf.
Oligocene	2.9	4.5	None	G., P.	G., P.	Highly emergent, except Gulf.
Lower Miocene	3.2	4.6	Marked G.	G., At., P.	G., At., P.	Highly emergent.
Upper Miocene	4.4	6.7	Decided P.	At., G., P.	At., G., P.	Highly emergent.
Pliocene	1.8	1.0	General uplift	At., G., P.	At., G., P.	Highly emergent.

In the column marked "Regional movements" is indicated the character of land movement for the times specified, which in most cases are times of folding. The border region so affected is also noted. This information is probably not accurate, but is thought to represent at least the major movements. It is not intended to record here the warpings of the areas of the continental seas, as these movements are thought to be too slight in amount to effect the major transgressions and emergences.

The column "Seas present" gives the names of all the bodies of water existing at each period. The letters are arranged according to the importance of the various seas—that is, according to the amount of area covered by them—the following seas being represented:

Ap = Appalachian sea.
At = Atlantic ocean.
Ar = Arctic ocean.
C = Cordilleran sea.
G = Gulf of Mexico.
H = Hudson sea.
L = Saint Lawrence sea.
M = Mississippian sea.
P = Pacific ocean.
S = Sonoran sea.

The column marked "Direction of flow of water—in or out" indicates the ocean transgressing (+ P. means from Pacific), and the direction of flow of the waters during an emergence (— G. means towards the Gulf).

The column "Rate of change of strand-line" shows the relative geologic rate at which the transgressions and emergences take place. The information in this column should be used cautiously, and especially in regard to emergences, for one's judgment as to the amount of time required to change a given fauna appearing above an hiatus may be decidedly at variance with fact when discovered.

Regional movements.—During the eleven periods of Paleozoic transgressions there were but three of land folding, and of these only one may be said to be noteworthy, as far as the area affected is concerned. This is the one of Onondaga time. The eleven emergences record nine periods of movement, of which three were decidedly great, the one at the close of the Georgic period, and the Taconic and Appalachian revolutions. Four others were less strongly marked (Shakopee, Onondaga, Chemung, and Kaskaskia), and the two remaining are of small significance (Utica and Fern Glen). Of the nine post-Paleozoic divisions of the table, two record no movement—the Triassic and Oligocene—that of the Eocene is not of special importance, while the remaining six are of much force, especially the Laramide revolution. In other words, of the thirty-two tabulated divisions of geologic time, fourteen record no movements, four only slight ones, and fourteen times there were marked movements.

As far as the North American continent alone is concerned, it appears as if the invasions or transgressions of the oceans had but slight connection with the ascertained land movements, but that the emergences were nearly always associated with folding or uplift. This was especially true of the revolutions closing the eras. It is also clear that the time divisions, as here delimited, were more often due to world causes—the ensemble of all movements—and that the major records were not established by the inadequate movements of the lands.

During the Paleozoic, more than at any time afterwards, tangential thrusts of the oceans caused synclinoria to form on the inner sides of the lands away from the ocean, and these were deepest immediately on the inner sides of the moved block. Such synclinoria were repeatedly flooded by the sea, were always narrow elongate waterways, and in the Ordovicic were complicated by subsiding seas, all having the same general trend as the main trough. Such invasions were apt to be even smaller than the minor transgressions, particularly along the Atlantic region. The thrusts from the Pacific seem to have been of a grander order, producing extensive and wide but shallow synclines.

These thrusts, it is thought, were also more or less directly connected with the buckling of the medial region of the continent, and in the continental seas produced the parmas of Suess (II: 34), the geanticlines of Dana (1895, 387), or the barriers of Ulrich and Schuchert (1902). As the thrusts were not only of the Atlantic and Pacific oceans, but of the Gulf of Mexico mediterranean as well, two sets of these barriers were developed nearly at right angles to each other, of which those having a north and south trend were by far the most effective. Where these intersected, nodes were produced that often appeared as islands or peninsulas in the continental seas, while the intermediate areas of the axis may have been submerged.

Owing to the variable loading and the irregular subsiding of the continental seas, their different basins were also variously warped, causing the strand-lines to alternate irregularly between positive and negative conditions. In other words, the strand-lines of continental seas were decidedly and locally oscillatory.

Thus far nothing has been said of vertical movements of the lands. There can be no doubt that, in addition to the more frequent tangential movements, decided vertical uplifts have also taken place, when great regions were lifted in mass. Such was the elevation of the peneplain of the Appalachian region, which was raised to a maximum of about 2,000 feet following the close of the Cretacic and during the Cenozoic, or the entire Rocky Mountain country, where far greater altitudes were attained in the late Cenozoic. Similar elevations may have taken place in the Paleozoic, but the area of the American continental seas records no marked movements of this character, as is proved by the presence to this day of these deposits over vast areas. Vertical uplifts of a minor order probably occurred as isostatic compensation due to continental loading, and possibly some of the emergences may be thus explained. The appearance of the land Siouxia in the Siluric may also be due to a low vertical uplift.

It would seem, therefore, that the movements of the land do not develop extensive continental seas, but rather the small seas occurring in times of emergence. These are the introductory seas of a new cycle, the sea invasions prophetic of the grand transgressions that are developed during periods of quiescence, denudation, sea-loading or filling, and the storing of earth stresses. The periodic discharge of these stresses is apparently the cause of the rhythmic oceanic subsidence and a new arrangement of the distribution of the seas over the continents. In other words, we agree with Hayford[129] that the earth is "a failing structure," but it fails on a grand scale, only periodically and to a very minor extent "every year, and probably every day and every hour." In this connection it may be well to give Hayford's views on this subject.

After an elaborate study of the geodetic evidence furnished by 507 stations in the United States, which consisted of "determinations of gravity and of determinations of deflections of the vertical," Hayford[130] concludes as follows:

> "The compensation of the excess of matter at the surface (continents) by defect of density below, and of surface defect of matter (oceans) by excess of density below, may be called the isostatic compensation" (28).
>
> "Let the depth within which the isostatic compensation is complete be called the depth of compensation. At and below this depth the condition as to stress of any element of mass is isostatic, that is, any element of mass is subject to equal pressures from all directions as if it were a portion of a perfect fluid. Above this depth, on the other hand, each element of mass is subject in general to different pressures in different directions, to stresses which tend to distort it and to move it" (29).
>
> "The evidence shows clearly and decisively that the assumption of complete isostatic compensation within the depth of 71 miles is a comparatively close approximation to the truth, that the assumption of extreme rigidity is far from the truth—that the United States is not maintained in its position above sea level by the rigidity of the earth, but is, in the main, buoyed up, floated, upon underlying material of deficient density" (32).
>
> "The fact is established by this geodetic investigation that the isostatic adjustment brought about by gravity has reduced the stresses to less than one-tenth of those which would exist if the continents and oceans were maintained

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[129] Hayford: Bull. Philosophical Society of Washington, vol. 15, 1907, p. 57.

[130] Hayford: Proc. Washington Acad. Sci., vol. 8, 1906, pp. 25-40.

by rigidity. This gives new and very strong emphasis to the idea that the earth is a failing structure, not a competent structure" (34).

"The indications are, therefore, that when an elevated area under which there is complete isostatic compensation is unloaded by erosion the underlying material to a depth of 71 miles increases in volume mainly because of chemical changes induced by the decrease in pressure, and partly also because of changes in the gases from solution to the free state. This increase in volume raises the surface. It also increases the pressure at each level above the 71-mile depth, and tends to bring it back toward the value which it had at that level before the unloading.

"This expansion process alone is not sufficient, however, to maintain an isostatic adjustment indefinitely.

"As the process progresses—a continuous expansion in the underlying material keeping pace approximately with continuous unloading by erosion at the surface—the pressure near the bottom of the expanding column will become considerably less than it is at the same level in other areas at which no unloading by erosion is taking place. So too, near the top of the expanding column the pressures will tend to be somewhat greater than at the same level in other areas. The result of these differences in pressure at any given horizontal surfaces will be to set up, sooner or later, a great slow undertow from the ocean areas toward the continents, and a tendency to outward creeping at the surface from the continents toward the oceans" (38).

"The undertow should be most powerful a short distance inside the continental borders, and hence the mountain building should be most active there. . . . Such mountain ranges should be unsymmetrical, thereby indicating that the pressure came from the ocean side" (39).

Emergences.—The emergences will next be considered. Of these there were at least fourteen of Paleozoic and Mesozoic time, nine of which are thought to have appeared rapidly. For eight the period of emergence was relatively short, while one—the Cayugan emergence—was of long duration. The other five appear to represent periods of slow emergence, as follows: The Chemung, Keokuk, and Kaskaskia emergences belong to one long interval of negative strand-line movement, beginning in the late Hamilton and persisting to the end of Paleozoic time, emphasized by the three above named sharp but small superimposed emergences of short duration. It may therefore be concluded that the emergences referred to were in reality also rapid, so that eleven of the fourteen represent, relative to the transgressions, short beats in chronology. The other three, being slow in their making, were of long duration and of great significance. These are: (1) The Taconic revolution, beginning early in the Trenton submergence and persisting well into the Siluric; (2) the Appalachian revolution, beginning in early Pennsylvanic time and continuing well into the Mesozoic, varying according to the region, and (3) the Laramide revolution, beginning in the Niobrara, and to all appearances enduring to the present lofty continent.

Thus there are minor and major emergences, and many more of the former than of the latter. All are thought to have the value of periods or systems, while the major ones arrange the minor beats into eras. Because of the wide distribution of the transgressions whose deposits are concordantly laid down, it is thought that total and actual continental uplift, followed by subsidence, can not be the explanation for these emergences. It must therefore be assumed that the continents are in the main unmoved, and that it is the oceanic areas which are periodically depressed, owing to the shrinkage of the earth, the result being an apparent elevation of the lands. The continents are chiefly horsts, unmoved during the periods of altered strand-lines. It may also be noted that the greater number of oceanic subsidences are relatively quick to appear, and that the emergence thus established is apt to be soon invaded by another transgression. Further, there are in America either five, four, or three of these minor emergences to one major one, as follows:

Georgic Franconia Shakopee Saint Peter Utica	Taconic revolution	Cayugan Chemung Keokuk Kaskaskia	Appalachian revolution (includes Permic)	Triassic Jurassic Comanchic	Laramide revolution

It is well known that the emergent period represented by the Laurentide revolution closing the Proterozoic was also of very long duration, but it is not known whether it was likewise of slow origin. At the close of each revolution the emergence of the North American continent was complete and the areal extent of the land in each case was about that of today, possibly even larger. The relative duration and importance of these revolutions may be expressed by the following order: (1) Laurentide, (2) Appalachian, (3) Laramide, and (4) Taconic.

The minor oceanic subsidences serve to divide geologic time into periods or systems. Their rhythm beats with equal regularity on the positive and negative strand-lines. During the early "Ordovicic" note the influence of the small Shakopee and Saint Peter emergences on the long persisting positive strand-line; also the effect of the small Chemung, Keokuk, and Kaskaskia emergences on the equally long negative strand-line of the Devonic and Mississippic.

The major oceanic subsidences gather, as it were, the minor beats into the eras, the critical periods of the earth. These major times of earth shrinkage and stress discharge are long in duration. During such times the continental borders are being remodeled into new frames of mountain ranges. The continents are then largest and remain longer emergent, as may be seen by the Laurentide, Taconic, Appalachian, and Laramide revolutions. These may be compared to the crests of great and slow moving waves recorded in the major changes of the strand-lines, and on these great waves are superimposed minor waves of more rapid movement, as seen in the various emergences establishing the periods or systems. These are the "secular vibrations" or "oscillations" of Dana.[131] There is still another order of waves, the wavelets of varying degree which delimit the formations and cause all local strand-lines to be decidedly oscillatory.

The emergences of the first and second order are seemingly due to the periodic shrinkage of the earth's mass, being the times when the earth's circumference is diminished. The lands as well as the oceans shrink; as, however, the latter areas subside relatively more and have nearly three times the areal extent of the former, it may be readily seen why the waters retreat more rapidly than they transgress the continents. During times of shrinkage parts of continents may also become down-faulted, thus adding greater area to the oceans and accentuating an already negative strand-line. Suess states that these subsidences "surpass all others in importance," while Chamberlin and Salisbury, in their Geology, affirm that "the master movements are the sinkings of the ocean basins" (I, 1904, 520).

The shrinkage of the globe at fairly regular intervals must also cause it periodically to revolve a little faster, the increased spinning probably adding a new factor in the more rapid and greater emergence of the lands toward the poles of both northern and southern hemispheres. At each one of the periods of the earth's shrinkage it is thought an equatorial protuberance appears, toward which some of the oceanic waters are likewise drawn. By equatorial protuberance it is not intended to convey the idea that an elevation of land or water, or both, in every case completely encircled the earth along this belt, but rather that somewhere in this region there was a compensating protuberance. It is postulated further that these elevations were very low, and that a heaping of 10 feet more of water above the normal in most cases, and in none more than 100 feet, would be sufficient to withdraw the average continental transgressions of the oceans. As the earth is a "failing structure," the protuberances slowly flatten down, and during this process the oceanic waters again gradually return toward the poles, thus adding their quota to the renewed transgression. Most of the North American inundations have come from the south, these floods being certainly more persistent in that part of the continent. This fact is made clearer by contrasting the percentages of the water-covered areas of North America with those of the United States

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[131] **Dana: American Journal of Science, vol. 22, 1856, pp. 342-347.**

(see table, page 499). By adding together all the percentages of the periods represented, North America will be found to have the sum of 559 against 695 for the United States.

The many pulsations of ancient Tethys across Europe, Africa, and Asia, and the far rarer Arctic invasions, furnish evidence of the same fact—that the equatorial waters are the more persistent. Tethys extended from Spain to India and China, and today is represented by the Mediterranean. These facts were also noted by Suess (II: 252).

On discussing the foregoing conclusions with Professor Barrell, he said that the relation between equatorial protuberance and periodic shrinkage could be given quantitatively, and it would then be seen whether or not the postulate had any real value. It will be seen from his statement that the amount of water periodically taken from the polar regions and heaped in the equatorial belt is in quantity more than sufficient for the periodic withdrawal of the continental seas. He writes as follows:

Influence of earth shrinkage on the distribution of continental seas. By Joseph Barrell.—The great movements which have broken up the earth's history into periods are, as Professor Schuchert indicates in this paper, in general characterized by broad continental emergences either slight or pronounced in character. Evidences of circumferential shortening are always local, and may or may not be observed, distinguishing especially those greater movements which have been classed as revolutions. But even the slight disturbances, when recorded by the recession of continental seas from quiescent continental areas, are thought to be due principally to subsidence of the oceanic bottoms, lowering in turn the general surface level of the waters of the ocean. All movements, therefore, which mark off periods are in all probability due to earth shrinkage, which for each of the greater revolutions may, according to Van Hise, amount to a radial shortening of from 8 to 16 miles. The momentum of the earth remaining constant, it follows that as a result of such shrinkage a greater speed of rotation must ensue.

According to recent studies by Chamberlin and others,[132] tidal friction has been a negligible factor during the known history of the earth; but even were it important enough and able to produce an appreciable secular slowing of the earth's rotation, temporary accelerations would result, accompanying the comparatively rapid shrinkage during the transition epochs which separate the successive periods. Chamberlin and his coworkers have shown that the figure of the earth could not have been greatly altered by this means, but Professor Schuchert has raised the question whether the acceleration may not have produced a slight heaping of waters toward the equator, sufficient to affect the distribution of the continental seas—seas that have often been so shallow that a change of level of 100 feet would markedly alter their limits.

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[132] The tidal and other problems. The Carnegie Institution of Washington, 1909.

If the residual stresses which could remain in the body of the earth after an epoch of shrinkage were small in comparison with those stresses resulting from the acceleration of the earth's rotation due to the shrinkage, then an adjustment of figure to this new speed of rotation would occur *as a part of the movement,* an adjustment which would involve the interior of the earth and would not be expressed by an equatorial heaping of ocean waters. As the slight equatorial bulging would not modify appreciably the character of the general deformation, there would be no visible evidence of the accompanying adjustment to a new figure in rotational equilibrium.

An equatorial heaping of waters accompanying earth shrinkage would therefore require an ability in the earth to retain residual stresses large in comparison with the small bodily stresses resulting from the slightly increased speed of rotation. Such a stress would operate through the whole body of the earth. It is readily seen, however, that the change in the earth's shape, due to the acceleration, must be but a small fraction of that involved in the shrinkage, and it is quite possible, therefore, that the undischarged centripetal stresses remaining after the shrinkage are still much larger than the superimposed stresses due to slightly increased rotation.

On this assumption it was sought to find to what extent a given shrinkage of the earth would cause an equatorial heaping of waters. For this purpose were employed the tables on pages 59 and 67 of "The tidal and other problems," by Chamberlin *et al.,* which permit a simple statement of the relations, with an error probably not greater than 5 per cent.

As the amounts of earth shrinkage involved in epochs of diastrophism are not even approximately known, any greater refinement in treating of the results would be useless. It is seen from these tables that a decrease of earth radius from 4,060 miles to 3,960, maintaining the La Placian law of density, would result in a shortening of the day by 4,419 seconds (page 59). A shortening of the day by 14,990 seconds involves the relative changes in radius given in the first two lines of the table, page 67. From these figures it may be readily computed that a general shrinkage of the earth to the extent of 1 mile in mean radius will result in an increase of equatorial over polar radius of about 95 feet; a shrinkage of 10 miles will result in a relative increase of about 950 feet. The results will be somewhat different according to whether the shrinkage is equable throughout the centrosphere or is concentrated chiefly in some portion of the earth. These possibilities, which can not be shown in the tables, increase the error perhaps to 10 per cent, and for the convenience of round numbers the equatorial bulging for each mile of radial shrinkage may therefore be spoken of as from 90 to 100 feet. In latitude 35 degrees the water level will suffer no change. At the poles it will sink some 60 feet, and at the equator it will rise about 35 feet.

Transgressions.—An analysis of the column in the foregoing table marked "Rate of change of strand-line" will show that of the eleven Paleozoic transgressions three moved rapidly over the land. These were the Saint Croix, Richmond, and Pottsville transgressions. The latter occurred at a time of loaded continental seas and high degrading Appalachia and Acadia. The Richmond transgression was a rapid duplication of the previous Trenton one, which flowed slowly and widely over a featureless land. It was seemingly due to the making of some small foreign land, which caused the rapid overflow. The other swift transgression (Saint Croix) was probably more apparent than real, the paleogeographic map of Acadic time as here presented being synthetic and embracing too much time. Two other transgressions were rapid, but were of small areal extent and fell in a time of long persisting emergence. These were the Fern Glen and Saint Louis invasions, which may have owed their swift expansion also to the formation of small extraneous lands. The six remaining inundations were slow in spreading, these being the Georgic, Ozarkian, Beekmantown, Trenton, Niagaran, and Onondaga transgressions. The last three were the largest and most significant of all, for they are also well recorded in most other lands, and were true transgressions in the sense defined by Suess. These six slow invasions were seemingly due to long periods of continental unloading into seas and oceans; there are no events of sufficient importance known to explain them otherwise. The Ozarkian and Beekmantown inundations were followed by that of the Trenton, and combined they made a more and more extensive transgression marked by two sharp and rapid retreats of the water.

During the Mesozoic there were four periods of continental seas. The first was the Triassic invasion of the Pacific coast, slow in spreading and culminating in the Upper Triassic. A second appeared and vanished rather rapidly early in the Upper Jurassic, causing the Logan sea. The third began early in the Comanchic, and was of slow spread. A rapid withdrawal of the water then followed, apparently succeeded by an equally swift return of the sea, causing the fourth and much enlarged transgression of early Cretacic time. Beginning in the Niobrara, this flood then slowly retreated, ending with the Laramie series and the Laramide revolution. It was undoubtedly this revolution, with its long-continued oceanic subsidence, that slowly withdrew the continental Coloradoan sea from the land. The principal Mesozoic transgressions are believed to be due to the same cause as those of the Paleozoic, namely, displacements of the seas and oceans by the land wash.

It has been said that the wearing away of the high lands and the transportation of this material into the sea results in the progressive inundation of the lands. Chamberlin and Salisbury[133] state: "It is estimated that the cutting away of the present continents and the deposition of the material in the ocean-basins would raise the sealevel about 650 feet (R. D. George)." Displacement of the oceanic level to this extent would inundate the entire medial region of present North America and produce a transgression not greatly unlike that of the Middle Siluric. This would bring into existence another large Mississippian sea in wide connection with the Saint Lawrence sea. The Arctic waters would have a broad sweep across the Canadian shield through Hudson bay, with another prolongation extending south from lakes Manitoba and Winnipegosis to some distance along the Red River valley, and there probably would be communication with the Mississippian sea across the Great Lakes. The faunas of this northern sea would not be sharply differentiated from those of the southern waters, because of the wide-open connection of both northern seas with the North Atlantic. There would be still other marginal overlaps that need not be described, for it is readily seen that in this way another great transgression would result without any secular changes in the North American continent. (The basis for this estimate is the Relief Map of Canada and the United States, published by the Geological Survey of Canada, 1900.)

Whether the continental materials were transported to the oceans or were unloaded into the continental seas would make no difference; the effect of displacement of the strand-line would be the same. In the latter areas the isostatic adjustment (due to detrital loading and warping) would cause some portion of the sea bottom to rise sufficiently to displace an amount of water equal to the mass of the displaced lithosphere.

During critical periods the continental margins are apt to be decidedly raised, and this elevation is thought to exceed the accumulated stresses produced during times of long quiescence. Dana[134] states: "After a mountain birth there has commonly succeeded a time of relaxed lateral pressure; and then occurred adjustments, largely by gravitation, in the moved masses or faulted blocks making chiefly down-throw displacements, besides producing new fractures and faults. Such displacements have taken place especially in the region of mountain plateaus, where the pressure was least." Such settling also adds its quota to the transgressions, but in all probability the total effect is small.

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[133] Chamberlin and Salisbury: Geology, vol. 1, 1904, p. 520.

[134] Dana: Manual of Geology, 1895, p. 386.

Oceanic participation in the transgressions.—Having examined into the causes of the various transgressions and emergences, the degree to which the different oceans have contributed to these results will now be set forth. The synopsis of the writer's paleogeography is tabulated in the columns "Seas present" and "Direction of flow of water—in or out."

It is seen that the *Atlantic ocean* has not made a very decided record from the standpoint of deposits and faunas. The Saint Lawrence sea has been the chief area of its extension, and while this sea and the straits across New Jersey have often sent their biota into the Mississippian sea, yet the northern Atlantic or Poseidon has had the least faunal control of all the oceans. Its waters often entered the Appalachian sea, but only three times did they dominate this basin, these occurrences taking place in the Clinton, the Salina, and the Lower Devonic intervals. From the physical side, however, the ocean has had a marked influence throughout the Paleozoic in elevating bordering lands and mountain chains, thus preventing the faunas of interior seas from mixing much with those of the Atlantic. In other words, the North Atlantic did not dominate the continental Paleozoic seas of North America, and during the Mesozoic it was practically non-existent.

During the early Paleozoic the *Arctic ocean* had a great influence. In the Middle and Upper Ordovicic and Siluric the waters of the Hudson sea dominated the continental seas, and through the Cordilleran sea had a marked effect in the Middle Cambric, the late Devonic, and early Mississippic. In the late Triassic, and again in the Middle Comanchic, the Arctic ocean overlapped the greater part of Alaska, while in the Cretacic it connected with the Gulf by way of the Coloradoan sea. At other times this ocean had no appreciable influence.

The *Gulf of Mexico,* as the southwestern part of Poseidon, has had the most continuous existence of all the great bodies of water, being present throughout most of the Paleozoic, Mesozoic, and Cenozoic eras. Its waters, however, have been confined to the eastern half of the United States. The only times when entrance of the Gulf was blocked were the Cambric, Salina, Chemung, late Permic, the greater portion of the Triassic, and most of the Jurassic. It was dominant throughout the Ordovicic, Clinton, Onondaga, most of the Mississippic, Pennsylvanic, Permic, late Jurassic, Comanchic, Cretacic, and Oligocene. Its influence, therefore, was most marked in the late Paleozoic and late Mesozoic.

The *Pacific ocean* was dominant during the early Paleozoic, before the Taconic revolution—that is, during the Cambric and early and late Ordovicic, when its waters extended to Appalachia. Subsequently, although often of marked influence, it became dominant only in the Upper Devonic, the early Mississippic, early Pennsylvanic, Permic, Upper Triassic, and late Jurassic.

It is thus seen that North America was most frequently and persistently inundated by the southern waters of the Pacific ocean and the Gulf of Mexico; in other words, by equatorial waters. This condition was rendered variable only by the floods from the Arctic ocean, which were decidedly great in the early Paleozoic, but later became spasmodic and much reduced in extent. In transgressions the Atlantic was practically a negligible factor, yet it often made its influence felt through the distribution of its faunas.

Oscillatory seas.—Suess was the first to point out the fact that strand-lines are oscillatory, but Ulrich has rediscovered this same truth in his studies of the areal distribution of the Ordovicic formations. The term, as here used, is applied to the third order of movements of the strand-lines, namely, those that delimit formations. As employed by Suess, the definition includes both major and minor oscillations, with special emphasis on the latter.

It has long been apparent that most formations represent local accumulations, yet few persons have distinctly realized the fact that these lenticular deposits are of extraordinary number and are delimited either by variations in the depth of the sea or by short intervals of emergence. Suess states that the oscillations "correspond for the most part with negative phases" of the strand-line, but to the writer they seem to be nearly as characteristic of the positive phases of the strand-line. The American Paleozoic continental seas consisted of very shallow waters. Any movement at any time must have affected the strand-line. As the continental seas were distinctly the receiving basins of detrital material, and as the load was very unequal in different areas of the same sea, it follows that each shallow basin must have constantly and locally altered its depth. Further, owing to unequal loading, the subsidence in these areas must have been unequal, with the result that the strand-lines of continental seas constantly fluctuated, but were always subject to the major negative and positive movements of the oceanic level.

Since the continental seas varied so remarkably in depth, extent, character of deposits, mineral content of waters, showed such constant fluctuation between shallow seas and marsh flats, and were highly sensitive to any change in climatic conditions, as that of summer and winter or of warm and cold climates, it is evident that the life of these seas must have developed under great stress, and was therefore subject to more rapid evolution than the life of the oceans. During times of transgression the marine faunas not only increased numerically in individuals, but the latter changed in form into new genera and species—"expansional evolution"—while the "provincial faunas" of the early part of the invasions, through intermigration, were more and more transformed into "cosmopolitan faunas." In times of emergence the faunas were largely killed off, unrelated stocks were brought into direct struggle with one another for the possession of food, the whole tendency being toward "restrictional evolution."[135]

Oceanic level.—No such condition as an oceanic level conforming to a regular spheroid exists. Where the land-masses are large and elevated, the oceanic level is attracted considerably higher than where these are small and low—a fact long since appreciated by geodesists in computations upon the form of the "geoid." At the present time the average height of the continents is about 2,200 feet, and it is estimated that this mass attracts the strand-line at least 300 feet higher than if the lands were reduced to sealevel. In this way may be explained some of the smaller overlaps during the early stages of times of emergence, as well as the appearance of small synclinal seas on the inner sides of moving blocks of land. As the high lands are rapidly eroded, these attracted seas and small synclinal seas are likely to disappear, and the waters thus released aid in a general eustatic elevation of the strand-lines in the low land areas.

Owing to volcanic activity throughout the geological ages, the waters on the surface of the earth have increased to the present volume. This was particularly so during the "formative eon" and the "extrusive eon," and the additions must have been considerable since the earliest Proterozoic or the "gradational eon."[136] Whatever the amount may have been since the Proterozoic, it does not appear to have had visible effect in raising the strand-line of any period. This extra water has been taken up apparently by the constantly enlarging oceans and the fragmentation of continental areas and their vanishing into the deeps, such as Davis strait, Denmark strait, Norwegian sea, equatorial Atlantic (Gondwana), etcetera.

As a vast amount of water has been added to the earth's surface during the geologic ages, and as nearly all of it has been added to the oceans, plus some of the material of the horsts, may we not have in these constantly increasing loads a further explanation why the oceanic areas are in general constantly subsiding?

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[135] Chamberlin: A systematic source of evolution of provincial faunas. Journal of Geology, Chicago, vol. 6, 1898, pp. 597-608.

[136] Chamberlin and Salisbury: Geology, vol. 2, 1906, p. 119.

DESCRIPTION OF THE PALEOGEOGRAPHIC MAPS AND CLASSIFICATION OF THE AMERICAN GEOLOGIC FORMATIONS INTO PERIODS AND ERAS

PALEOZOIC AND NEOPALEOZOIC

Before defining the term Paleozoic, it will first be necessary to call attention to the nomenclature of the earlier era or eon, the Proterozoic, which is interpreted by Chamberlin and Salisbury (II: 162) thus:

> "To the Proterozoic era is assigned the time . . . between the close of the Archean and the beginning of the Paleozoic." "Proterozoic, as here used, is a synonym for Algonkian as used by the U. S. Geological Survey."

The question that now arises is, Does the nearly forgotten term Protozoic of Sedgwick[137] cover the same ground? The original definition is as follows:

> "Class I—Primary stratified groups
>
> "Gneiss, mica slate, etcetera, Highlands of Scotland and the Hebrides. Crystalline slates of Anglesea and the S. W. coast of Carnarvonshire.
>
> "The series generally without organic remains; but should organic remains appear unequivocally in any parts of this class, they may be described as the Protozoic system.
>
> "Class I (*a*). The crystalline slates of central Skiddaw forest, and the upper Skiddaw slate series. The whole is inorganic and intermediate between Class I and Class II."

In the following year Murchison[138] proposed the same word, as follows:

> "But the Silurian, though ancient, are not, as before stated, *the most* ancient fossiliferous strata. They are in truth but the upper portion of a succession of early deposits which it may hereafter be found necessary to describe under one comprehensive name. For this purpose I venture to suggest the term *Protozoic Rocks*, thereby to imply the first or lowest formations in which animals or vegetables appear."

A better conclusion may be reached as to the idea which these geologists intended to convey by also quoting the words used by Sedgwick when he proposed the term "Paleozoic." He states:

> "Class II, or *Paleozoic series*
>
> "This class includes all the groups of formations between Class I and the old red sandstone; and is subdivided as follows:
>
> "1. *Lower Cambrian system.*—All the Welsh series under the Bala limestone. The two great groups of green roofing slate and porphyry on the north and

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[137] Sedgwick: Proceedings of the Geological Society of London, vol. 2, 1838, p. 684.

[138] Murchison: The Silurian system, vol. 1, 1839, p. 11.

> south side of the mineral axis of the Cumbrian mountains. A small part of the slates of Cornwall and South Devon. ? A part of the slate series of the Isle of Man, etcetera.
>
> "2. *Upper Cambrian system.*—A large part of the Lammermuir chain on the south frontier of Scotland. A part of the third Cumbrian group, commencing with the calcareous slates of Coniston and Windermere. The system of the Berwyns and South Wales. The slates of Charwood forest. ? All of the North Devon and a part of the South Devon series. The greater part of the Cornish series. . . . .
>
> "3. *The Silurian system.*—The upper part of the third Cumbrian group, chiefly expended in Westmoreland and Yorkshire. The flagstone series of Denbighshire. The hills on both sides of Llangollen. The region east of the Berwyn chain. The regions described in the papers of Mr Murchison, from which the types of the system are derived. The lowest part of the culmiferous series. ?
>
> "Over all the preceding comes the Old Red Sandstone" (685).

From the foregoing definitions, it is clear that Paleozoic originally embraced the fossiliferous formations beneath the Old Red sandstone—that is, the continental phase of the marine Devonic, to and including the "Cambrian." This base, then, was a very uncertain one, and included Proterozoic rocks, as this term is now understood. In other words, Paleozoic, as originally defined, comprised in the main what now belongs to the fossiliferous systems—Cambric, Ordovicic, and Siluric. As for the nonfossiliferous deposits also included, these may here be set aside.

Protozoic, as the type areas on which this term was based are now comprehended, certainly embraced a considerable portion of the equivalent formations included under Paleozoic, and also much that is now referred to the Proterozoic. The words "the series generally without organic remains" might easily be made to apply to the generally unfossiliferous Proterozoic era. It is there evident that this term is a very vague one—a sort of "dump box," in fact, into which all the unresolved formations were then thrown. Hence there is no need of reviving the term, nor should it displace the names far better defined—Proterozoic and Paleozoic.

Since Sedgwick's use of the term Paleozoic, it has been extended to embrace all the systems above the Proterozoic and beneath the Mesozoic. In recent years, however, the great significance of the Taconic revolution has been recognized in America, and in 1895 Dana thought it advisable to separate this era into two "sections," as follows:

> "Paleozoic time is naturally divided into two sections at the break between the Lower and Upper Silurian. This boundary line is marked in the history by an epoch of mountain-making in eastern North America and western Europe, and by a somewhat abrupt transition in the animal life of the seas. . . .
>
> "The first of these sections, the *Eopaleozoic*, was characterized by the fact of almost universal seas over the continental area, and of universal marine life, and also by the more specific Paleozoic fact, that marine invertebrates . . .

were displayed under nearly all their grander types before the close of this section of Paleozoic time; and also that the highest division of the Animal Kingdom, Vertebrates, was represented by species of the inferior type of Fishes.

"The second of the sections, the *Neopaleozoic*, was characterized by the gradually increasing extent of dry land over the continental area, and the covering of the emerged surface with land plants, and finally with great forests. . . .

"The Eopaleozoic section was . . . the time of the Reign of the Invertebrates, and prominently of Trilobites; the Neopaleozoic, in its Upper Silurian and Devonian eras, the time of the Reign of Fishes, and in the Carbonic era, that of the Reign of Amphibians" (460).

With Dana it must be agreed that the Taconic revolution is a "critical period," and that in geologic classification it has the value of other critical periods. The writer therefore proposes that the Paleozoic be divided into two independent eras. For the earlier portion, or Dana's Eopaleozoic, it seems wise to return to the original usage of Paleozoic, but modified to agree with present knowledge. Paleozoic will therefore supplant Eopaleozoic, while Neopaleozoic will be preserved with the limitations as defined by Dana.

As to the nomenclature of eras and systems, etcetera, the writer further proposes to follow the rules adopted by the International Geological Congress in regard to a unification of nomenclature. Geikie[139] has summed up these rules as follows:

"The International Geological Congress has, since 1881, laboured strenuously to effect some reform in this matter, but only with partial success. The scheme adopted at the last meeting (Paris, 1900) comprised the following stratigraphical subdivisions: 1st Order: Eras of time, represented by Groups of strata, Paleozoic, Mesozoic, Cainozoic. 2nd Order: Periods of time, represented by Systems of strata, as in the four great Paleozoic systems. 3rd Order: Epochs of time, represented by Series of strata. 4th Order: Ages of time, represented by Stages of strata. 5th Order: Phases of time, represented by zones of strata. . . . The divisions of the second order are all made to terminate in *ique*. . . . Or Cambric, Siluric, Devonic, as they would be written in English. The divisions of the fourth order are meant all to end in *en* (*an* in English), as Bartonian, Portlandian, etc."

The eras and periods will be drawn as follows:

The eras are delimited by the "critical periods" in the earth's history. They are marked by long periods of extensive mountain making and periods of long and decided emergence. The old condition of things is brought to an end, and is followed by a greatly altered physical aspect of the lands and seas. These changes also greatly affect the life of both land and sea, their results being easily discernible in the life of the opening periods of the eras, the Paleozoic, the Neopaleozoic, the Mesozoic, and the Tertiary or Neozoic.

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[139] Geikie: Text-book of Geology, 2d edition, 1903, p. 859.

The systems or periods are delimited by diastrophic conditions that as a rule are also worldwide. Each period is marked by a new transgression of the oceans invading the lands. These are usually slow in progress and of long duration, yet are followed by a more rapid withdrawal of the continental seas. Theoretically, the periods are separated from one another by the two highest successive nodal points of emergence on the curve chart; practically, however, it will not be easy to decide which of the definitely localized formations of emergent times belongs to this or that period. In some cases the faunas will determine this point, and in others the making of paleogeographic maps. Where the seas have been continuous from one period to the next, however, as on Anticosti, the line of separation must either be an arbitrary one or be drawn on the evidence of faunas elsewhere recorded by the oscillatory strand-lines.

PALEOZOIC ERA (emended)

Georgic Period (new)

(Lower Cambrian, Georgian, or Olenellus epoch of Walcott)

See plate 51, and pages 482, 483

Table of Georgic Formations

House range, Utah Walcott, 1908	Mount Bosworth, British Columbia Walcott, 1908	Georgia, Vermont Walcott, 1891	Smith sound, Newfoundland Walcott, 1900
Pioche shale 125	Mount Whyth shale, limestone, and oolite 390	——Break——	Break
		Argillaceous shale 3,500	
Prospect Mountain quartzite 1,375			
	Saint Piran shale and sandstone 2,705	Limestone and shale 1,700	
At Big Cottonwood, Utah 11,750 + sandstone and shale		Quartzite 50	Placentia shale, limestone, and basal conglomerate 900 +
Waucoba Springs, Inyo county, Cal. 5,670 + of sandstone, shale, and limestone (1,290)	Lake Louise shale 105	Shale with thin limestone 3,500 Georgia shale 200	
	Fairview quartzite 600 +	Basal limestone 1,000	

From the beginning of the Paleozoic, paleogeography can be made out with much certainty, but back of that period all is shrouded in obscurity, owing to the absence of a paleontologic record. On the basis of fossils, there should not be the slightest hesitation in distinguishing between the marine Paleozoic and Proterozoic rocks, and as a rule these are also easily determined by angular unconformity. The late Proterozoic formations, however, are very rarely fossiliferous, yet when organisms do occur, the fauna is so inadequate and so different from that of the Olenellus period as to leave no question regarding its stratigraphic position.

Over vast areas of Canada, on both sides of Hudson bay, are found coarse fragmental deposits, often regarded as of Cambrian age, but latterly Canadian geologists are inclined to pronounce these formations Proterozoic in time. All such unfossiliferous strata are eliminated from the present maps. Sandstones and conglomerates of great thickness, and containing no evidence of life, should be treated with considerable caution when mapping them historically as marine deposits, for many such are now turning out to be continental in character. For this reason, and owing to the accumulation of many new facts since 1891, the late Georgic map herewith presented differs essentially from the equivalent one published by Walcott at the date mentioned.

From the extent and position of the Lower Georgic invasion, it is inferred that the North American continent was larger during the late Proterozoic than at any subsequent period.

The Georgic seas existed as synclinal seas along both sides of the North American continent, the Atlantic waters being present in a long but narrow trough to the northwest of Acadia and Appalachia. From Labrador to Alabama the life represented is essentially that of the *Olenellus thompsoni* fauna, though a knowledge of it has been acquired mainly in Vermont and eastern New York. These facts were long ago pointed out by Walcott, who has ascertained most of what is known regarding the American Cambrian. He also determined that these encroachments of the Atlantic and Pacific did not occur along the continental platforms as did those of Tertiary time, but that the Paleozoic was ushered in with interior or continental seas, a fact that holds good throughout the Paleozoic and for most of Mesozoic time.

On the accompanying map, communication with the Atlantic has been effected not only through the Saint Lawrence embayment, but also across northern New Jersey. In the latter state, during the Paleozoic, the deposits in question are very frequently found quite near the ocean, and when an Atlantic fauna is present in the strata of the Appalachian region, as is often the case in later times, there can be no doubt that during the Georgic the Atlantic also entered the southern interior by this strait.

Along the Pacific the sea became widespread in the Great Basin region to the southeast of the positive element Cascadia. Here again the same phenomena existed as along the Atlantic—that is, interior seas, with great depth of sediments originating along the inner sides of positive elements that evidently were moving inward and away from the oceans.

At the close of the Georgic the first marked post-Proterozoic crustal movement of the Appalachian region occurred, and a complete land barrier was thrown up, which effectually prevented the later Cambrian faunas of the Pacific realm from passing into the Atlantic. Previous to this movement the Olenellus biotas of the Pacific and Atlantic were very much alike—that is, they were cosmopolitan—but as yet it is not known where the intercommunication existed. It may have been across northern Mexico, but more probably occurred across southern Mexico or Central America.

The longest and the least broken Cambrian sections are those of the Cordilleran sea. Walcott[140] has recently given the details of these magnificent sections. The Waucoba Springs sequence, of Inyo county, California, has a total thickness of 5,670 + feet, of which the upper 1,300 feet consist of limestone. This is the oldest Paleozoic anywhere known. It comprises all of Georgic time, and in the lower third is marked by *Archæocyathus, Ethmophyllum, Mickwitzia, Trematobolus, Holmia,* and rarely by *Olenellus. Holmia rowei* ranges through 3,150 feet, and *H. weeksi,* of higher zones, through 1,370 feet. The genus *Olenellus* (including *Holmia*) extends through 4,900 feet of this section, *Holmia* in the lower portion and *Olenellus* in the higher part.

Other characteristic fossils of the Cordilleran Georgic are *Olenellus gilberti, Protypus, Microdiscus, Kutorgina cingulata, Swantonia, Nisusia,* smooth *Billingsella, Hyolithellus,* and *Salterella.* The Pioche shale at the top of the Georgic still has *O. gilberti,* but Middle Cambrian forms here begin to appear, as *Zacanthoides* and *Crepicephalus.*

In the region of Georgia, Vermont, and in eastern New York occur many others—*Olenellus thompsoni, Mesonacis vermontana, Holmia* or *Elliptocephala asaphoides, Bathynotus holopyga, Protypus, Microdiscus, Conocoryphe, Hyolithellus, Salterella, Nisusia, Swantonia, Kutorgina cingulata,* and *Paterina labradorica.* At York, Pennsylvania, Wanner found *Holmia walcottana.*

The Protolenus fauna of Matthew[141] appears to be best placed at the base of the Middle Cambrian or Acadic.[142]

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[140] Walcott: Smithsonian Miscellaneous Collections, no. 53, 1908, pp. 167-230.

[141] G. F. Matthew: Trans. New York Academy of Sciences, vol. 14, 1895, pp. 101-153.

[142] C. D. Walcott: Proc. Washington Academy of Sciences, vol. 1, 1900, p. 302.

From southern Newfoundland, among others, Walcott reports *Holmia bröggeri, Microdiscus, Hyolithellus, Fordilla troyensis. Paterina labradorica,* and *Helenia bella.* The Labrador biota is closely allied to that of Vermont and New York.

These lists bring out anew the well known fact that the Georgic faunas are cosmopolitan, and that *Olenellus* and *Holmia,* the two leading trilobites, are common to the Pacific and Atlantic. In the Pacific realm *Olenellus* may have given rise to the eurypterids, while in Atlantic waters *Holmia* appears to have developed into *Paradoxides.* In the former ocean, also, originate the large-tailed trilobites, which swarm in the Middle Cambrian and dominate these deposits as far east as the Appalachian region.

The writer has not yet been able to make more than one paleogeographic map of the Georgic period, but it will probably not be long before additional ones can be developed. Perhaps the transgression will then be shown to have been from the south, in all probability earliest in the Cordilleran sea of the Great Basin area. With *Holmia* present at York, Pennsylvania, and on Newfoundland, it may be shown that at these places the Atlantic began its earliest invasion of the continent, and finally that there was some withdrawal of the continental seas along the Atlantic region owing to the secular changes that here closed the Georgic period. In the main, it is this evidence that distinguishes the Lower Cambrian as a period or system. At first there was a widely emergent land, but slightly transgressed by the oceans, and finally even the small Atlantic seaway vanished, being brought about by an uplift that here greatly altered the former topography of the land. The name Georgic has been chosen for this period to conform with Georgian series and Olenellus epoch as used by Walcott.

If the sediments of the Cambrian are compared with those of the Ordovician, it will be seen that the former consist chiefly of coarse clastic deposits, this being especially true of the Georgic. For many years Walcott has persistently collected the faunas of the latter period, yet today he probably has less than 250 American species from the thousands of feet of strata. This scarcity of faunal development, which is composed mainly of trilobites with chitinous tests and of brachiopods having phosphatic shells, suggests cool waters, but of equable temperature, as shown in the cosmopolitan character of the Olenellus fauna. The widespread Lower Cambrian tillites (Australia, China, Norway, ? South Africa) of course furnish positive evidence of at least local glacial conditions. On the other side, however, is the equally marked fact of the occurrence of thick reefs of *Archæocyathus* in Inyo county, California.

These are likewise plentiful in Labrador, New Siberia, Spain, and Sardinia. Such sponge-like corals in thick reefs suggest rather warm waters and seem to indicate that the glacial occurrences had but little effect on the oceans. That there was a change toward warmer waters throughout the remainder of the Cambrian is shown by the far larger number and variety of species, the greater abundance of lime-secreting animals, the vaster number of individuals, and by the more and more persistent calcareous deposition of the seas.

Acadic Period (new)

(Middle Cambrian, Acadian, or Paradoxides epoch)

See plate 52, and pages 483, 484

Table of Acadic Formations

House range, Utah Walcott, 1908	Mount Bosworth, British Columbia Walcott, 1908	New Brunswick Matthew, 1896 Walcott, 1900	Saint Croix river of Minnesota-Wisconsin Berkey, 1898
Weeks limestone 1,390			
		——— ? Break ———	———Break———
	Eldon limestone 2,728		
Marjum limestone 1,102		*Paradoxides davidis* zone	Franconia glauconitic sandstone 100-200
Wheeler shale 570		*Paradoxides abenacus* zone 75	
	Stephen shale and limestone 640		Dresbach shale and sandstone 150–200
Swasey limestone 340		*Paradoxides eteminicus* zone 25	
Dome limestone 355			Lowest sandstones 0–1,000
Howell limestone 435	Cathedral limestone 1,595	*Paradoxides lamellatus* zone	
			———Break———
Spence shale 20		*Protolenus* zone 108	
Langston limestone 205			

The Middle Cambrian in the Cordilleran sea appears to have continued the Georgic seas without break, and early extended the invasion into the Arctic ocean. The Pacific flood also transgressed the continent with a wide distribution of the Asiatic faunas as far east as Appalachia and Acadia. Beyond these lands there were at this time distinct Atlantic faunas; in the Atlantic the Paradoxides faunas, and in the Pacific the Olenoides and big-tailed trilobite biotas. The Saint Croix invasion seems to have spread somewhat rapidly across the continent, particularly in the north, where the continental seas also vanished earliest during the Franconia emergence. In the southern parts of the United States the marine sequence appears to be a longer and more perfect one, with less clastic and more organic deposits. In the northern portion of the Mississippian sea nearly all the strata are sandstones and shales. The writer is not yet able to map these two events separately, and thus bring out more clearly the cycle of sea movements.

The Acadic of the Pacific realm of North America is marked by the presence of the trilobite genera *Kootenia, Zacanthoides, Bathyuriscus, Asaphiscus, Neolenus, Olenoides, Dorypygella, Dorypyge, Damesella,* and *Ogygopsis.* Toward the top appear *Crepicephalus texanus, Billingsella coloradoensis* (also in lower portion), and *Eoorthis remnichia,* these likewise passing into the western Upper Cambrian. No genus of brachiopods having several common species is restricted to the Acadic, but in the lower portion *Micromitra pannula* abounds, and in the higher, *M. sculptilis.* According to Walcott (1908), the first appearance of *Illænurus* determines the base of the Upper Cambrian.

The Acadic is the time of greatest abundance and differentiation of inarticulate brachiopods. Throughout the world at this time there are 31 genera and 243 species of brachiopods, while in the Georgic there are 20 genera and 75 species, with 23 genera and 137 species for the Upper Cambrian (Walcott). During the latter time the inarticulates rapidly drop out as stratigraphic factors, while the articulate calcareous-shelled forms as rapidly differentiate and become some of the best time guides of subsequent Paleozoic periods.

In the upper Mississippi valley the Franconia horizon has *Billingsella coloradoensis, Agnostus josepha, Chariocephalus whitfieldi, Conocephalites diadematus, Lonchocephalus hamulus,* and *Ptychaspis.* The Dresbach zone is marked by *Lingulepis pinniformis, Dicellomus politus,* and *Agraulos convexus.* At Eau Claire, Wisconsin, the lower sandstones have *Agraulos woosteri* and *Conocephalites calymenoides.*

In the argillites at Braintree, Massachusetts, occur *Paradoxides harlani, Ptychoparia rogersi,* and *Agraulos quadrangularis.*

The Atlantic fauna has recently been discovered by Edson in an intraformational conglomerate at Saint Albans, Vermont. Here Walcott[143] confirms the presence of *Paradoxides* in a fauna of thirteen species. This fact shows how near the Atlantic waters approached those of the Pacific realm on the western side of the Green Mountain barrier without intermingling. Their present position, however, is due to much northwesterly thrusting.

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[143] Perkins: Annual Report of the Geological Survey of Vermont, 1907-1908, p. 209.

In southern Newfoundland, on Manuels brook, the Acadic begins with a conglomerate having pebbles holding fossils of the Georgic strata below (Walcott, 1900, 315). Above this layer, which is 18 inches thick, follow argillaceous shales having a depth of 170 feet. These are succeeded by a thin limestone zone marked by the presence of *Paradoxides,* the latter extending 66 feet higher in a series of shales interbedded with limestone. Here occur *Paradoxides davidis* and *P. bennetti.* Apparently a stratigraphic hiatus exists above these beds, followed by the Olenus fauna.

The base of the Acadic of New Brunswick has the Protolenus fauna. In the end this horizon may prove to be better placed at the top of the Georgic. Its guide fossils are *Botsfordia pulchra* and the trilobites *Micmacca, Protolenus,* and *Bergeronia.*

The higher or Paradoxides beds here have, among others, an abundance of *Agnostus, Agraulos, Liostracus, Conocoryphe, Ctenocephalus,* and *Paradoxides* (six species); also *Protorthis billingsi.* This fauna and the other Atlantic biota are closely allied to the Paradoxides faunas of Wales and Sweden but less so with that of Bohemia.

Ozarkic (new: Ulrich) *or Cambric* (restricted) *Period*

(Upper Cambrian, Saratogan, or Dikelocephalus epoch; in part, also, much of the basal Ordovician of geologists)

See plate 53, and pages 484, 485

The type area for the faunal succession of this period is the Ozark region of southern Missouri and northern Arkansas. Here the "Ozark series" of Broadhead is divided by Ulrich[144] as follows:

Jefferson City dolomite....................	50–250 feet.	Eroded at the top.
Roubidoux formation	70–225+ "	
Gasconade limestone	450–650 "	
Elvins formation	0–120 "	

In the Arbuckle mountains of Oklahoma, the Ozarkic, consisting of limestones and dolomites, is not less than 4,000 feet thick. Ulrich states that "it represents one of the longest uninterrupted depositions of pure limestone and dolomite of which we have knowledge." The Ozarkic embraces all the Arbuckle limestone to the top of its massive middle member.[145]

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[144] Bain and Ulrich: Bull. U. S. Geological Survey, no. 267, 1905, pp. 13-35.

In the southern Appalachians this period comprises considerable of the Knox dolomite. According to Ulrich, the upper limit "is drawn at the top of the main cherty mass of the Knox dolomite as exhibited in Copper ridge," and the base begins "with the lower non-cherty member of the Knox." In the middle Appalachians this time is represented within the comprehensive Shenandoah limestone. In southern Pennsylvania by the Conococheague formation. In New Jersey "the greater lower part of the Kittatiny dolomite" is of this period.

In New York and Canada the Ozarkic "is represented by the greater lower part of the Little Falls dolomite, the Potsdam sandstone, the Theresa formation and Division A, and B of Brainerd and Seely's Champlain Valley Calciferous" (Ulrich; for further detail, see his paper in the present volume).

In Minnesota and Wisconsin this period is manifested in the Shakopee, New Richmond sandstone, Oneota dolomite, Jordan or Madison sandstone, and the Saint Lawrence dolomites and shales.[146]

In the accompanying map the Lower Ozarkic or the Ozarkian transgression is plotted at its maximum. It embraced the Lower Knox, Lower Arbuckle, Lower Kittatiny, Elvins, Gasconade, Division A of Beekmantown, Theresa, Little Falls, Potsdam, typical Saratogan, Saint Lawrence, and Jordan or Madison. It is seen that the Mississippian sea derived most of its life from the Gulf of Mexico, and distributed it far to the northeast into the Saint Lawrence trough, yet is thought not to have passed out here into the northern Atlantic. The faunas of New Brunswick are wholly different, and are in harmony with those occurring in Europe at this time. As there appears to have been some slight intermingling of the Atlantic and the interior continental sea, a passage has been opened into New Jersey. This exchange, if it existed, is not marked, though later there was free communication between the two areas.

As none of the later Ozarkic formations seem to have been present in the Cordilleran sea, and possibly also none in Acadia, the Shakopee emergence must have been of wide extent. The Mississippian sea was greatly restricted in the northeast, and all the land here had emerged up to the dotted line drawn on the map. As thus delimited, the Upper Ozarkic comprised Oneota, Shakopee, Roubidoux, Jefferson City, and the upper part of the middle Knox. The emergence being continued, the Mississippian sea was finally almost entirely withdrawn, for there is an erosion interval above the formations named. The seas retreated southward.

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[145] Taff: Professional Paper, no. 31, U. S. Geological Survey, 1904, pp. 22-23.

[146] Berkey: American Geologist, vol. 21, 1898, p. 377.

In a general way it may be said that the Ozarkic period begins with the trilobite genus *Dikelocephalus* and the first distinct molluscan fauna. Ulrich has collected about 200 species of this period, nearly all of which are new and await description. The trilobites and inarticulate brachiopods (greatly reduced in species) are still Cambrian in aspect, while the new faunal feature consists in a rapid evolution, in form and size, of the coiled gastropods and of both straight and coiled cephalopods. The latter are distinguished from those of subsequent periods by the exceedingly close arrangement of the septa. No bivalves are here represented, no bryozoa, graptolites (*Cladophora* are present), crinoids, starfishes, nor ostracods (all the so-called forms are determined by Ulrich to be phyllopods). During the Ozarkic period, for the first time in the history of the earth, the animals living in the sea, especially the mollusks, began a general secretion of calcareous skeletons. Of course, the sponge-like corals of the Georgic had the "lime habit" much earlier, but until the Ozarkic in none of the earliest faunas did the secretion of lime become a factor among many types of invertebrate animals. That this mode of protection was of great benefit to the creatures possessing it, is seen not only in the rapid rise of genera and species in the Ozarkic, but also in the marked increase in the size of individuals. This evolution is particularly noticeable in the middle and upper beds of this period.

In the lower part of the Ozarkic system of Minnesota and Wisconsin occur *Agnostus disparilis, A. parilis, Illænurus quadratus, Dikelocephalus minnesotensis, D. pepinensis, Aglaspis barrandi* (the oldest limuloid), *Owenella antiquata, Holopea sweeti, Ophileta, Raphistoma,* etcetera.

The conglomerates of the "Quebec series" also bear this fauna, but in the Saint Lawrence trough the actual formations are unknown. These species have been assembled by Walcott.[147] This fauna chiefly brings to mind those from near Saratoga Springs, New York, where Walcott collected *Dikelocephalus hartti, D. speciosus, Agraulos saratogensis, Lingulepis acuminata,* etcetera.

Ordovicic Period of Authors

The Ordovician is usually regarded as a period shorter in duration than the "Cambrian," with a complexity of faunas not more varied nor difficult of interpretation than those of the Siluric. Accompanying this memoir are nine maps covering this time; at least five additional ones will have to be made in order to bring out clearly the geographic position of the various transgressions and emergences of the Ordovician seas. That this subject is very complex may be seen from the detailed description by Ulrich, given elsewhere in the present volume.

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[147] Walcott: Bull. U. S. Geological Survey, no. 81, 1891, p. 151.

The fact that there were so many inundations and emergences, with hordes of faunas local and provincial in character, makes it evident that Ordovician time was of far longer duration than is usually supposed. There seem to be here represented about 25 per cent of Paleozoic time, a length in strong contrast with the duration of other periods.

In constructing these maps a great mass of unpublished data has been utilized, accumulated chiefly by Ulrich in connection with the collections of the U. S. National Museum and the U. S. Geological Survey. During the past four years these maps have been subjected to frequent discussion and emendation, yet are still inadequate, as far as presenting a final and definitely determined geographic distribution of the various faunas is concerned.

In the Appalachian region are shown topographic forms unknown to the present world, for it has been found necessary to assume long and narrow land barriers, on either side of which are formations both physically and faunally dissimilar. In studying these much constricted barriers, it must be borne in mind that the geographic base on which these times are plotted is that of today. That the entire Appalachian and Piedmont region has been foreshortened many miles is well known; overthrusts up to 25 miles in length can also be pointed out, and here may be repeated the statement of Claypole that eastern Pennsylvania has been abridged at least 75 miles, yet no one is able to state how great has been the reduction in the total northwesterly thrust and crushing of Appalachia, Acadia, and their Piedmonts. Therefore, if a geographic base could be projected which truly represented Ordovician geography, it would undoubtedly be seen that these narrow ridges not only widened considerably, but took on forms not now suspected. Whatever shape the barriers may have assumed, however, those here illustrated serve merely as means to bring out the fact that synchronous faunas wholly distinct now lie close together.

In Arkansas and at times also along the southwestern side of Appalachia from Alabama into southern Virginia, occur Lower Ordovician faunas which it is thought can not be associated with those of the Pacific realm. They have the Atlantic impress, and are derived from the same faunas as those found in the Saint Lawrence sea and to the east of lake Champlain and the Hudson river. In the main these are graptolite faunas, having many species in common with Great Britain and Sweden, and it is a remarkable fact that on the two sides of the ocean these faunas should be so much alike.

The principle of diastrophism combined with these guide fossils has convinced Ulrich and the writer that they can no longer subscribe to the generally accepted delimitation of the Ordovician or Lower Silurian system. It will be here shown that this period had three cycles of sea movements. In other words, there were three submergences of North America, two great and one small, each of which was followed by a small or a very marked emergence. This so-called system may therefore be divided into three periods—the Canadic, the Ordovicic, and the Cincinnatic.

Canadic Period (new: Ulrich)

(In part Calciferous, Canadian, or Beekmantown of geologists)

See plates 54 and 55, and pages 485, 486

As far as published work is concerned, a great deal of obscurity exists regarding the relationship and distribution of the formations composing the Canadic series. Ulrich has studied these deposits in most regions throughout the United States, and in this volume he presents a digest of the information thus acquired. He and the writer jointly herewith give two paleogeographic maps, one showing the time of greatest transgression and another the emergence about half completed.

This period or system is bounded below by the Ozarkic and above by the Stones River-Chazy series of the Ordovicic. The type area for this period of the Mississippian sea is lake Champlain of northeastern New York. Of Brainerd and Seely's[148] Calciferous section, it embraces their divisions C, D, and E (not their A and B, which belong in the Ozarkic period). Combined, these divisions have a thickness of about 1,200 feet. The fauna has been described by Whitfield[149] and Ruedemann.[150] With divisions A and B, these compose the Beekmantown of Clarke and Schuchert.[151] The section downward is as follows:

E. Thin-bedded magnesian limestone, 470 feet thick. Has *Helicotoma similis, Murchisonia confusa, Bucania* (?) *tripla, Bathyurellus glandicephalus, Primitia seeleyi, P. cristata, P. gregaria, Orthoceras perseus,* and *O. xerxes.*

D4. Thin-bedded blue limestone alternating with slaty layers, 100 feet thick. Fort Cassin horizon. Has *Rhinopora prima, Dalmanella evadne ?, Protorthis cassinensis, P. minima, Hemipronites apicalis, Billingsella* (?) *primordialis, Syntrophia lateralis, Tryblidium* (4 species), *Cliospira lirata, Euomphalus circumliratus, Raphistoma, Plethospira cassina, Lophospira cassina, Ecculiopterus volutatus, Calaurops lituiformis, Fusispira obesa, Maclurea affinis, Orthoceras* in many species, *Cyrtoceras, Gomphoceras, Piloceras explanator, Eurystomites kelloggi, E. imperator, Tarphyceras champlainensis, T. farnsworthi, T. seeleyi, Schroederoceras eatoni, Trocholites internastriatus, Asaphus canalis, Bathyurus* (?) *seeleyi, Harpes cassinensis, Nileus striatus, Ribeiria compressa, R. ventricosa.*

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[148] Brainerd and Seely: Bull. American Museum of Natural History, vol. 3, 1890, pp. 1-23.

[149] Whitfield: Ibidem, vol. 1, 1886, pp. 293-345. Ibidem, vol. 2, 1889, pp. 41-65. Ibidem, vol. 3, 1890, pp. 25-39.

[150] Ruedemann: Bull. 90, New York State Museum, 1906.

[151] Clarke–Schuchert: Science, 1899, p. 878.

D3. Sandy thin-bedded limestone, 120 feet thick.

D2. Magnesian limestone with some sandstone, 75 feet thick. Has at Phillipsburg, Canada, *Syntrophia armanda, Orthoceras* (7 species), *Cyrtoceras aristides,* and *Dikelocephalus missisquoi.*

D1. Thin-bedded blue limestone, 80 feet thick. At base has *Ophileta complanata.* Near Beekmantown, Whitfield (1889) collected in this zone *Dalmanella macleodi, Triplecia* (?) *radiata, Maclurea* (?) *sordida, Hormotoma gracilens, Lophospira calcifera, Liospira prævium, Trochonema exile, Euconia beekmanensis, Ecculiomphalus* (?) *priscus, Metoptoma* (?) *alta, Tryblidium pileolum, T.* (?) *acutum, Holopea turgida, Bathyurus conicus, B. seeleyi,* and *Cyrtoceras* (2 species).

C. Dolomite, magnesian limestone, and sandstone, together 350 feet thick. Toward the bottom has *Scolithus minutus.*

This same fauna is also known at Phillipsburg, Quebec; again in part on the Mingan islands; and finally in great development, but with localized species, in northern Newfoundland, in zones F, G, H, I, K, L, M. The facies of these various Canadic faunas are unknown in Europe.

In Pennsylvania, around Chambersburg and Mercersburg, Ulrich reports that this system has at least 2,500 feet of pure magnesian limestone; farther west at Bellefonte, in the central part of the state, over 4,000 feet. In the southern Appalachian area, the period is present in the Knox of Alabama and in the Wells Creek uplift of western Tennessee. The latter area is most closely related faunally to the Yellville of northern Arkansas. In the upper Mississippi valley there are no Canadic deposits, yet in the Mohawk valley of New York the upper portion of the Little Falls dolomite belongs to this period. In the southern Cordilleran region these strata are likewise present, but north of Colorado the evidence is rather against their existence.

A fauna entirely different in character, preserved in black shales and sandstones, occurs in the Levis trough of the Saint Lawrence sea. Here are present the *Tetragraptus, Dichograptus,* and *Phyllograptus* faunas, all decidedly in harmony with those of western Europe. This same element was recognized by Gurley and recently by Ulrich in Arkansas, where the latter found a fauna very much like that of the lower Arenig and middle Skiddaw of Wales.

In the Saint John region, New Brunswick, G. F. Matthew has reported the presence of this period in the lower part of his Bretonian, where faunas occur that have a decided Atlantic and European impress. At the base is the *Parabolina spinulosa* zone, also, with *Lingulella lævis, Plectorthis lenticularis, Clitambonites* (?) *johannensis,* and *Rafinesquina* (?) *atava.* This is followed by the *Peltura scarabæoides* zone, having *Agnostus bisectus, Parabolina heres, Protopeltura acanthura, Leptoplastus latus, Sphæropthalmus, Ctenopyge, Dictyonema flabelliforme confertum, Bryograptus kjerulfi,* and *Clonograptus* (?) *spinosus.*

In the third zone occur *Obolella* (?) *gemmula, Obolus refulgens, Linnarssonia, Acrotreta,* and *Dictyomena flabelliforme acadicum.*

The next is the Tetragraptus zone, with *Parabolinella, Cyclognathus, Orthoceras, Styliola primæva, Dalmanella* (?) *electra major, Orthis panderiana, Bryograptus patens, Dictyonema delicatulum, D. quadrangulare, Clonograptus flexilis, Dichograptus logani, Tetragraptus quadribrachiatus, Didymograptus patulus,* and *D. indentus.* This or the previous horizon, or both, Ruedemann has found on Hoosick river, at Schaghticoke, New York.

The Canadic of the Atlantic type is also present in eastern Ellsmere land, on the north side of the Archer plateau to the north of cape Sabine. Here, in the dolomite, Schei collected *Leptograptus* and *Anomocare.*

This period is marked by the first appearance of true graptolites, bryozoa (though still rare here), ostracods, and asaphoid trilobites. The gastropods and cephalopods, too, are larger and show better development than in the Ozarkic.

The Canadic closed with a widespread retreat of the waters from the northern and northeastern areas (see the Saint Peter map for area emerged), thus bringing about the Saint Peter emergence, the marine interval being represented in the Ozark region of southern Missouri by the Crystal City sandstone, which is here 0–200 feet in thickness. Ulrich states: "The Saint Peter falls within, or more probably a little more than fills, the gap between the Beekmantown [of the Canadic] and the Stones River" of the Ordovicic system. In most places the record between these two periods is broken. The Saint Peter sandstones of the upper Mississippi valley are by some regarded as eolian desert sands, while others look upon them as marine deposits. May they not be the late Canadic regolith reworked by the sea of the succeeding transgression? Such being the case, these reworked sandstones must be referred to the Ordovicic system.

Ordovicic Period (new emendation)

(In part the Ordovician of authors)

For the detailed descriptions of the various formations of this system see Ulrich's paper, and for the areal distribution of the seas the five maps—(1) Stones River-Chazy, (2) Lowville, (3) Lowest Trenton, (4) Late Trenton, and (5) Utica (plates 56-60). Also see pages 486, 487.

Table of Ordovicic Formations

Mohawkian.	Utica of New York. Mastigograptus fauna.	
	Trenton of New York. In the main, Galena of Iowa, Illinois, etc. In the Atlantic province, the *Climacograptus caudatus*, *Corynoides curtus*, and Magog graptolite zones.	
	Kimmswick of Illinois and Missouri. Generally a break here.	The horizon of the Normanskill graptolite beds of the Atlantic province.
	Black River of New York. Generally a break here.	
	Lowville of New York. Represented in Moccasin of Tennessee. Generally a break here.	
Chazian....	Upper Chazy of the Champlain valley. This horizon is included in the Holston of Tennessee, 800–900 feet thick. Plattville of Wisconsin = Carter or top of Upper Stones River.	
	Stones River (Lower and Middle) of the Southern states. Lower and Middle Chazy of the Champlain valley. General break.	
	Canadic period.	

The Saint Peter emergence of the Canadic period was followed by a slow and very decided transgression of the sea. The invasion, however, was highly oscillatory, moving in and out of the areas, yet in general the successive floods were greater and greater, and finally in Trenton time was developed the greatest inundation that had ever covered the North American continent. More than one-half of its area and somewhat less than two-thirds of the United States were then under the sea. Here again the Appalachian-Acadian land barriers were effective in preventing the intermingling of the Pacific and Atlantic faunas. The life in the Pacific, however, now took on a more cosmopolitan character, which was in all probability due to the mixing of the Pacific elements with those of the Arctic region, for at this time occurred the first northern Paleozoic inundation. Very similar faunas are found in Baffin Land, Manitoba, Minnesota, New Jersey, and Tennessee. Today the Arctic is regarded by oceanographers as but a part of the Atlantic, but in Ordovicic times it had little communication with that ocean, and many of the Black River, Trenton, and Richmond fossils remind one of those of the Baltic region, an area intermittently connected with England and the Atlantic. At this time the Atlantic fauna still had its own characteristics and was again marked by graptolites of the Normanskill, Magog, and *Climacograptus caudatus* zones, common to eastern America and Great Britain.

Late in the Trenton the transgression by that name began to disappear, first in the Arctic region, then in the Pacific and Gulf areas, culminating with the Utica in the Utica emergence. This withdrawal of the sea was so widespread, while the deposits that were subsequently laid down on these lowest Trenton strata are usually so absolutely conformable, that one is forced to the conclusion that some oceanic area had been deepened, thus causing the waters to flow off the continent. During this retreat of the sea the first evidence of those peculiar heavily armored fishes belonging to the Ostracoderms appears in cleanly washed beach sands and less abundantly in dolomites at three widely separated places in Colorado and Wyoming. They are now all fragmentary and seem to have been washed into the sea by the rivers. From this can it be inferred that during some earlier inundation the marine ancestors of these fishes were retained upon the land in relict seas, and under the stress of evanescent waters became modified into the armored double-breathing animals that gave rise later to the true fishes? Such being the interpretation, the marine fishes must then have been derived from land fishes, as suggested by Chamberlin and Salisbury.

Cincinnatic Period (new)

(Upper Ordovician or Cincinnatian of authors)

See plates 61 and 62, and pages 487-489

See Ulrich's paper for the detailed discussion of this system.
Type area: Southwestern Ohio and southeastern Indiana.[152]

Table of Cincinnatic Formations

Siluric.			
Richmondian ..	Elkhorn zone, 50 feet.		
	Whitewater zone, 75 feet.		
	Saluda zone, 5–23 feet.	Thebes.....	Mississippi valley.
	Liberty zone, 30–50 feet.	Maquoketa.	
	Waynesville zone, 60–80 feet.	Fernvale...	
	Arnheim zone, 80 feet.		
Maysvillian....	Mount Auburn zone, 20 feet.		
	Corryville zone, 60 feet.		
	Bellevue zone, 20 feet.		
	Fairmount zone, 80 feet..	In part, Lorraine of New York.	
	Mount Hope zone, 50 feet.		

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[152] Nickles: American Geologist, vol. 32, 1903, pp. 202-218. Journal of the Cincinnati Society of Natural History, vol. 20, 1902, pp. 49-100. Cumings: Thirty-second Annual Report of the Department of Geology and Natural Resources of Indiana, 1908, pp. 607-1189.

Edenian	McMicken zone, 60 feet. Southgate zone, 120 feet. Economy zone, 80 feet..	In part, Lorraine of New York. Frankfurt and Pulaski of New York.

Ordovicic.
Fulton (= Utica), 5 feet.

The Ordovicic period was closed by the Utica emergence. As has been seen, this emergence was widespread, and even the greater part of the early Utica sea was finally eliminated. This condition apparently continued into the Lorraine. If the necessary maps could be made, however, it is thought that the paleogeography would show either a stationary or a slightly enlarged sea during the Frankfurt and Lorraine, this having been brought about by the Taconic revolution of long duration in the Appalachian region. It began in the Trenton and persisted nearly to the close of the Cincinnatic, during which time the older Paleozoic strata were folded all the way from southern Virginia to Newfoundland. In this eastern region, therefore, the life of the later Utica, Frankfurt, and Lorraine was greatly affected not only by the large influx of mud and sands, but even more by the shallowing of the Appalachian waters. In the northeast, in the Saint Lawrence sea, these effects were perhaps more pronounced than in the Appalachian trough south of New York.

West of the Cincinnati axis, all of America was elevated above the sea during the Utica, Lorraine, and earliest Richmondian, but in later Richmondian time there was again widespread submergence. Nearly all of the Utica is absent at Cincinnati and to the south, but to the north the deep-well borings show more and more of this formation. With the Edenian, which also includes the Frankfurt of New York, the sea again returned to the Cincinnati area, and this invasion is thought to have marked the beginning of the Cincinnatic period. To the east of the Cincinnati axis the Appalachian sea was fairly constant in areal extent to the close of the Lorraine, when more and more of the marine waters here subsided. In the Cincinnati region, the Maysvillian sea was apparently continued without break into that of the early Richmondian. This sea then spread west of the axis and united with the widespread flood of the later Richmond, which came in from the Arctic and Pacific areas. In extent this transgression stands second in comparison with that of the Trenton submergence.

On faunal grounds there is decided evidence for placing the Edenian and Maysvillian, together with the Richmondian, in the Cincinnatic system. These three series are united by about 5 per cent of the fauna that is common to all of them, while of the Edenian species about 14 per cent pass into the Maysvillian, and of the latter about 12 per cent occur in the

Richmondian (Nickles, 1902). The Edenian and Maysvillian faunas represent the return of the Mohawkian faunas, but somewhat changed. In the early Richmondian, however, there was an influx of migrants from a new area, probably the North Atlantic (Anticosti), forming the *Rhynchotrema capax* and *R. perlamellosa* faunas.

At the close of the Richmondian all further Cincinnatic records of marine deposits are absent in the interior region. The continent remained emergent for a long time, and when the next short oscillations of the oceans occurred the faunas represented are very different, having several spire-bearing brachiopods and other reminders of the Siluric. The dividing line between the Cincinnatic and Siluric is usually drawn at the top of the Richmondian, but this delimitation will now have to be changed, as it fails to recognize a long interval elsewhere recorded. On Anticosti may be studied a complete section bridging this lost interval, and through 1,134 feet of limestones may be traced the gradual transition of the life of the highest Richmondian into that of the earliest Siluric. The Cincinnatic, therefore, can not be closed with the Richmondian, but must be continued until a considerably later period—one yet to be determined by the Anticosti record.

NEOPALEOZOIC ERA

Siluric or Ontaric Period

See plates 63-71, and pages 489-491

On the basis of their faunas the American Siluric deposits are geographically divisible into three provinces, the best known being that of the Atlantic realm, which is represented on the continent by three subprovinces—the Saint Lawrence sea, the Appalachian trough, and the Indiana basin of the Mississippian sea. These waterways also have the longest sequence of formations—in fact, showing a nearly complete representation of the Siluric system. The next best known province is that of the Hudson sea, whose faunas are of Arctic and northern European derivation. This sea appeared in the United States long after the beginning of the Siluric and vanished with the Guelph. The third province is that of the Cordilleran sea, evidently Pacific in origin, but of which little is known. The following synopsis of the crinoids, brachiopods, and trilobites will bring out the relationship of the eastern provinces:

Table of Widely Distributed Siluric Formations

Series or epochs	Western New York	East of Cincinnati axis, Ohio	East of Cincinnati axis, Kentucky	West of Cincinnati axis, Indiana, Kentucky, Tennessee	Wisconsin	Iowa
Niagaran	Guelph of Ontario			Break Decatur, 63–70 feet	Break Guelph	
		Break Cedarville		Louisville: Brownsport: Lobleville, 17–76 feet Bob, 15–75 feet Beech River, 37–101 feet	Racine (Reef limestone) Upper Coral beds, 75 feet	
	Lockport, 130 feet	Springfield		Dixon, 18–44 feet Lego, 25–46 feet Waldron, 2–9 feet	Lower Coral beds, 70 feet Byron, 140 feet	Break Bertram. Coggan Gower: Anomosa, 60 feet Le Claire (Reef limestone), 80 feet
	Rochester, 85 feet Irondequoit, 14 feet Same fauna	West Union Niagara shales, 50–100 feet Dayton	Break Alger, 83–143 feet Indian Fields, 15–20 feet	Saint Clair: Laurel, 25–33 feet Osgood, 10–22 feet Break	Maryville, 15–57 feet Break	Hopkinton, 200 feet Break
Anticostian or Alexandrian	Clinton of western N. Y.: Williamson, 24 feet Wolcott (Furnaceville), 14 feet Sodus Small break Medina (Oneida)	Break Ohio Clinton, 20–150 feet Break	Break Brassfield, 13–19 feet	Break Ohio Clinton, 0–20 feet Edgewood, 0–4 feet Girardeau, 0–40 feet		

Of crinoids, Weller[153] has determined that the following genera of northwestern Europe are also present in the Chicago area (northern Illinois, southeastern Wisconsin, and Iowa), but not elsewhere in the United States: *Botryocrinus* (1 species), *Corymbocrinus* (2), *Crotalocrinus* (1), *Marsupiocrinus* (1), *Melocrinus* (1), *Petalocrinus* (2), and *Pycnosaccus* (1). As crinoids are very sensitive to environment and change rather rapidly, this list is proof of direct migration from Europe. Further, in the same area occur other genera that are found elsewhere in the United States. These are: *Callicrinus* (New York and Tennessee), *Eucalyptocrinus* (widely distributed), *Gazacrinus* (widely distributed), *Ichthyocrinus* (New York), *Lecanocrinus* (widely distributed), *Lyriocrinus* (widely distributed), *Myelodactylus* (New York and Tennessee), *Periechocrinus* (New York and Tennessee), and *Thysanocrinus* (New York and Tennessee). But few of the species are common to two areas. In other words, the majority of these crinoids are of one province—that of the Hudson sea and the Arctic realm. The genera comprising the second lot are more widely distributed, geologically and geographically, and are common to the Arctic and Atlantic realms.

The crinoid genera of the New York basin are also common to the area west of the Cincinnati axis and south of central Indiana—that is, the Indiana basin. These are: *Calceocrinus* (not in the Chicago area), *Callicrinus, Eucalyptocrinus* (a few species are common to the two areas), *Euchirocrinus* (not in the Chicago area), *Gazacrinus, Homocrinus* (not in the Chicago area), *Ichthyocrinus, Lecanocrinus, Lyriocrinus, Macrostylocrinus* (widely distributed in America), *Mariacrinus* (not in the Chicago area), *Myelodactylus, Periechocrinus, Pisocrinus* (not in the Chicago area), *Stephanocrinus,* and *Thysanocrinus.* In other words, these crinoids are of one province—that of the Mississippian sea—and belong directly to the Atlantic realm. Further, 5 genera of the Mississippian province do not occur in the Hudson province, and 7 genera of the latter area are unknown in the southern region.

At present the corals of the Siluric have little stratigraphic value. They begin to be common in the Rochester, from thence up to the Guelph reefs occurring at different horizons, and judging from published lists are about the same throughout. This is especially true of the Mississippian and Hudson seas. Corals are never abundant in the Saint Lawrence sea except on Anticosti, where the small reefs appear earlier than any of those in the Mississippian sea. These forms are now being determined at Yale.

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[153] Weller: Bull. Chicago Academy of Sciences, vol. 4, 1900, pp. 1-153.

Many of the Siluric brachiopod genera of America also group themselves readily into two distinct realms—the Arctic and Atlantic. To the Hudson sea are restricted the following genera: *Capellinia, Orthotropia, Dinobolus, Monomorella* (both occur in the Saint Lawrence sea), *Rhinobolus,* and *Trimerella.* It is very significant that all the platform-bearing oboloids are of the Arctic realm or of northern Atlantic waters.

In the three continental seas having Atlantic connections—the Saint Lawrence, Appalachian, and Mississippian—there are many genera restricted to these areas, most of which are also represented in Europe. These are: *Anabaia, Anastrophia* (may have representation in the Hudson sea), *Atrypina, Delthyris, Dictyonella* (may be in the Hudson sea), *Gypidula, Hindella, Homœospira, Hyattella, Mimulus, Orthostrophia, Reticularia, Scenidium, Streptis, Stricklandinia* (out of 16 species, only 2 in the Hudson sea), and *Uncinulus* of the *stricklandi* type.

The trilobites are usually excellent indicators of provincial connections, and as those of the American Siluric are practically all in harmony with those of western Europe, it must be assumed that the Atlantic has been the realm where these forms have developed. They are also good travelers, for Van Ingen has identified three European species in Arkansas—*Acidaspis quinquespinosa, Deiphon forbesi,* and *Staurocephalus murchisoni.* Further, of the 105 American Siluric species listed by Weller (1907), at least 17 have a wide geographic range and occur in two provinces. The trilobites as a rule, therefore, appear to have a long range in time, certainly longer than the crinoids, but are not so persisting as the brachiopods.

During the time of the Clinton and early Rochester, a series of migrants from the permanent basin of the Gulf of Mexico appear in the Mississippian sea on the west side of the Cincinnati axis. Many of these trilobite genera also occur in Europe, and later find their way into the province of the Hudson sea. These are, according to Weller (1907): *Acidaspis, Ampyx* (restricted to the waters of the Gulf), *Arctinurus, Ceratocephala, Ceraurus, Corydocephalus, Cyphaspis, Dalmanites, Deiphon, Dicranopeltis, Encrinurus, Metopolichas, Odontopleura, Phacops* or *Acaste, Proetus, Sphœrexochus,* and *Staurocephalus.* Other and northern Atlantic genera are: *Bronteus* and *Homalonotus.* Still later migrants restricted to the Hudson sea are: *Harpes* and *Illœnus.* In the Chicago area Weller has described 12 species of the last named genus, and there are 2 other forms from the same province. In other words, of the 17 American Siluric species of *Illœnus,* 14 are found in the area of the Hudson sea.

The known trilobites of the American Siluric are, therefore, of the Atlantic and Arctic realms. The great majority of genera, however, are from the southern waters of the Atlantic, and many of these also find their way into the northern waters of the Hudson sea.

Saint Lawrence sea.—On the island of Anticosti, in the Gulf of Saint Lawrence, there is a complete transition from the Cincinnatic into the Siluric. The line of division between these two systems must here at least ever be an arbitrary one, the determination of which is now being worked out at Yale. On Anticosti the Siluric apparently terminates near the base of the Rochester. Many of the species of this area are not only European in aspect, but are also found in the Clinton formations of the Appalachian trough.

Another fine, even longer, but far less fossiliferous section is that of Arisaig, Nova Scotia, recently restudied by Twenhofel[154] and the writer. This succession of faunules, while clearly of European affinity, differs markedly from all others of the Saint Lawrence sea, a condition probably due in part to the rapid accumulation of muds and sands in this area, and also to different sea ways. Farther to the northwest, in the Bay de Chaleur, at Black cape, near Richmond and about Port Daniel, may be studied other long sections of the Chaleur group, which continue the Anticosti section certainly as high as the Guelph. Some of these fossils have been described or listed by Billings. Near Dalhousie, and again about Gaspé, may be seen the beds that continue into the Helderbergian, but unfortunately they are almost unfossiliferous.

Acadian trough.—Faunas similar to the foregoing, but far more sparse in species, are also known in eastern Maine, buried in a vast mass of volcanic material said to attain a thickness of 46,000 feet. Among others, here occur the two European guide fossils *Conchidium knighti* and *Cardiola interrupta.*

In folio 149, U. S. Geological Survey, is described the Ames Knob formation of Penobscot bay, Maine, which has a thickness of 580 feet. The fauna was first listed by Beecher, and the list, somewhat changed, is repeated here. It contains Clinton forms in the lower half of the series, while the upper portion has a fauna typical of the Rochester shale. Volcanic activity had begun in this area at this time, since two of the red shale beds are composed of volcanic dust.

Appalachian trough.—Very similar faunas are again seen in the Appalachian trough extending from central New York into Alabama. Entrance from the Atlantic was effected in two places: in the north across New Jersey and in the south by way of the Gulf of Mexico into Alabama. These biota are as yet very imperfectly known, but have been described in part by C. A. White, Foerste, Prouty, and Ruedemann. The earliest Siluric fauna of this trough is contained in the fossiliferous Upper Medina, 120 feet in depth, as exposed in the Niagara River gorge. The more important fossils are: *Arthrophycus harlani, Dædalus archimedes, Helopora fragilis, Lingula cuneata, Camarotœchia* cf. *neglecta, Whitfieldella oblata* (these shells are of large growth and far too large to be of Cincinnatic age), *Modiolopsis orthonata, M. primigenius, Pleurotomaria* (?) *pervetusta, P.* (?) *littorea, Bucanopsis trilobatus,* and *Isochilina cylindrica.* At Hamilton, Ontario, less than 40 miles from the Niagara gorge, associated with these fossils in this horizon are others that are clearly Clinton species. This is best shown in the Bryozoa. These strata, and those of Dundas and Flamborough Head, are usually referred to the Clinton, but in the field hold the place of the Medina. In Pennsylvania, Maryland, and Virginia the equivalent horizon is the Tuscarora, or White Medina, sandstone. Ulrich refers the Medina to the Cincinnatic, yet to the writer this fauna seems distinctly younger than anything he has seen referable to the later Richmond. It is very closely related to the Clinton. On the other hand, if the additional fossils listed by Grabau[155] have been acquired by him, there can be no doubt of the Siluric age of the Medina sandstone.

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[154] Twenhofel: American Journal of Science, vol. 28, 1909, pp. 143-164.

The next higher formation of this trough, the Clinton, is marked by: *Palæocyclus rotuloides, Monograptus clintonensis, Retiolites genitzianus venosus, Anoplotheca hemispherica, Pentamerus ovalis, Stricklandinia lens, S. salteri, S. davidsoni, Brachyprion corrugata, Chonetes, Cornulites, Beyrichia lata,* and *Calymmene clintoni.*

The higher Niagaran strata are marked by *Atrypa reticularis, Reticularia bicostata, Spirifer crispus, Homœospira evax, Camarotœchia obtusiplicata, Dalmanites limulurus,* and *Homalonotus delphinocephalus.*

Mississippian sea.—On the west side of the Cincinnati axis, in the Indiana basin, appear the earliest Siluric deposits of the Mississippian sea, which were first pointed out by Ulrich and Savage.[156] The faunas are clearly of Atlantic origin. In southwestern Illinois, above the Cincinnatic deposits, occurs the Girardeau, with *Rafinesquina mesacosta, Leptæna rhomboidalis, Schuchertella missouriensis, Rhynchotreta, Homœospira, Cornulites tenuistriata, C. incurvens, Platyostoma, Strophostylus, Acidaspis halli, Cyphaspis girardeauensis,* and *Encrinurus.* A little higher is the Edgewood zone, with new additions, as *Atrypa rugosa, A. putilla, Hindella, Whitfieldella billingsana, Clorinda, Platystrophia, Schuchertella subplanus, Dalmanites danæ,* and *Lichas breviceps clinto-*

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[155] Grabau: Journal of Geology, vol. 17, 1909, p. 238.

[156] Savage: American Journal of Science, vol. 25, 1908, pp. 431-443. Ibidem, vol. 28, 1909: 516–519.

nensis. This is followed by the Ohio Clinton horizon of wide extent, from Oklahoma to Ohio, marked by *Triplecia ortoni, Stricklandinia triplesiana, Atrypa marginalis, Orthis flabellites, Plectambonites transversalis, Rhinopora verrucosa, Phœnopora magna, Pachydictya bifurcata, Favosites favosus, Halysites catenulatus, Stromatopora,* etc. In the Anticosti section it is seen that this so-called Clinton, or the *Triplecia ortoni* zone, is older than the true Clinton of the Appalachian region. The older Clinton, therefore, is here mapped as the Ohio Clinton. Ulrich has discovered that in northeastern Alabama this same fauna underlies the Appalachian Clinton with the *Anoplotheca hemispherica* fauna.

These are the early Siluric faunas of the Gulf region, the first oscillations that finally terminated in the Louisville transgression. In the earliest stages of this transgression not more than 6 per cent of the North American continent was covered by the continental seas, and about 12 per cent of the United States. At the height of the invasion about 36 per cent of both areas was inundated. The waters finally receded somewhat beyond the stage represented at the opening of the Siluric, for Manlius time shows the figures to be 5 and 10 per cent respectively for the two areas above mentioned.

The various formations that record this transgression first appear in the Mississippian sea, and later in the Hudson-Arctic sea. They are arranged in the Siluric table.

The Guelph faunas are distinguished from those of the Louisville and equivalent horizons by an almost complete absence of cystids and crinoids. The corals are scarce and are of the genera *Favosites* (3 species), *Syringopora* (1), *Halysites* (2), *Heliolites* (1), and *Stromatoporoidea* (6). Of brachiopods, practically no other forms are found than *Trimerella* (5 species), *Rhinobolus* (2), *Monomorella* (6), *Pentamerus oblongus, Conchidium occidentale,* and *Clorinda ventricosa.* The guiding pelecypod is *Megalomus canadensis.* The Guelph is especially distinguished by gastropods, of which there are more than 50 species. Many of these are large and nearly all are thick shelled. Of nautiloids, there are at least 20 species belonging to genera known in the Racine. Large *Leperditia* are also present. The trilobites are not conspicuous, and *Eurypterus* is rare.[157]

Cayugan emergence.—The Niagaran transgression attained its maximum spread toward the close of Louisville time. Early in the Guelph the sea began to retreat, first in the Appalachian trough and next in the Indiana basin, where the Decatur is thought to be of this time. A little later a general subsidence was in progress in the Hudson sea, and finally the greater part of the American continent became emergent. This was at the beginning of the Salina group, and from this time to the close of the Siluric the continental seas were North Atlantic in origin, their extension being restricted to the northern Appalachian and the Saint Lawrence seas.

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[157] Whiteaves: Paleozoic Fossils, vol. 4, 1906, and Clarke, Memoir no. 5, New York State Museum, 1903.

The seas of Cayugan time in the main were not normal marine waters. They were shallow pans, in which locally red and black shales, with salt, gypsum, and water limestones, were deposited. The life was Atlantic in origin, the principal eurypterids and ceratiocarids having marked relationship with those of Scotland and Wales, and to a lesser degree with those of the Baltic area. Even in the Saint Lawrence trough, the deposits of this time are as devoid of life as those of the Appalachian sea.

Toward the close of the Siluric in the Monroe group normal marine conditions gradually became dominant, and there was an appearance of life prophetic of the Helderbergian of the Devonic. The various formations of the Cayugan series are as follows:

Table of Cayugan Formations

		New York		Michigan and western Ontario (Grabau, Jour. Geol., 1909)
		Western New York	Eastern New York	
Cayugan Series	Monroe group.		Manlius, 75 feet Rondout, 40 feet Cobleskill, 6 feet	Lucas Amherstburg Anderdon Flat Rock } Upper Monroan
	Salina group.	Bertie, 60 feet Camillus, 50–300 feet Syracuse Vernon } 600 feet Pittsford, 20 feet	Rosendale Wilbur Binnewater High Falls Shawangunk	

During the Siluric there was much land throughout the Rocky Mountain region, from Mexico into the Arctic area, and it was only on the eastern side of this land that the Pacific spread into the Cordilleran sea by way of the Great Basin and the Arctic ocean. In the Sonoran sea, at El Paso, Texas, there was another Siluric transgression. Of these western faunas little is as yet known. Kindle[158] reviews all the known Rocky Mountain occurrences. In California a few Siluric fossils have been found in the

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[158] Kindle: American Journal of Science, vol. 25, 1908.

Montgomery limestone.[159] On the lower Ramparts of the Porcupine, in Alaska, Kindle[160] reports a dolomite series estimated at 2,500 feet in thickness. The fossils listed indicate Lower Niagaran time. In southeastern Alaska there is even a thicker series of limestones, with additional argillites that range up into the Guelph.[161]

Devonic Period

See plates 72-77, and pages 491-493

It has been seen that the Siluric closed with most of the North American continent emerged. This condition continued with slight marine oscillations throughout the Helderbergian and Oriskanian epochs. During these intervals the continent was never inundated more than 9 per cent and the United States 14 per cent. The faunas prophetic of the Devonic appeared in the earliest of these invasions—that is, the Coeymans—and rapidly took on the aspect clearly seen in the later Oriskanian.

Late in Oriskanian time the Decewville formation of cleanly washed beach sands, with Atlantic faunas, spread westward through New York into Ontario, and at the same time the Gulf of Mexico embayment, with Brazilian faunas, progressed northward along the western side of the Cincinnati axis.

This furnished the introduction of the fourth decided Paleozoic inundation, which attained its climax in the late Hamilton, and persisted, with a little emergence toward the close of the Chemung, into the Kinderhookian. In areal extent this submergence was identical with that of the Siluric. The Gulf faunas of Onondaga time are of a more decided warm clear water sea, apparently unrepresented in South America. This sea brought the second widespread coral reefs into the interior region. These reefs are best developed at Louisville, Kentucky; Columbus, Ohio; Ontario, and western New York, spreading north into the Hudson Bay region and eastward across the Taconics into the Connecticut trough and the Saint Lawrence sea. Thus the Onondaga is made up of two faunal elements—a larger and dominating biota derived from the south, and a smaller, not especially different element, but well represented by cephalopods, from the North Atlantic, together with many Oriskanian descendants and some hold-overs.

In the area of the Great Basin there is another series of faunas beginning with Helderbergian time, and apparently persisting unbroken into

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[159] Diller: Bull. 353, U. S. Geological Survey, 1908, p. 16.

[160] Kindle: Bull. Geological Society of America, vol. 19, 1908.

[161] Kindle: Journal of Geology, vol. 15, 1907.

Table of Devonic Formations

Series		Western New York	Eastern New York	Gaspé	Indiana basin	Oklahoma	Iowa and Missouri
Neodevonic	Chautauquan	Chemung. Shumla Laona and Long Beards Cuba High Point	Catskill In the main continental		Ohio	? Woodford	Break State Quarry
	Senecan	Portage. Portland Dunkirk Angola Rhinestreet Cashaqua Middlesex Genesee Tully	Oneonta Ithaca Tully	Break	Probable break	Break	Lime Creek Cedar Valley (Callaway) Upper Wapsipinicon
Mesodevonic	Erian	Hamilton Moscow } Moscow Tichenor } Moscow Canandaigua } Ludlowville Centerfield } Ludlowville Shaffer Marcellus (and Stafford) Onondaga	Hamilton Marcellus Onondaga Schoharie	Gaspé Marine below, continental above	Sellersburg and Silver Creek of Indiana Delaware and Olentangy of Ohio Jeffersonville of Indiana Columbus of Ohio	Break	Lower Wapsipinicon (Independence at base) Break
Paleodevonic	Oriskanian	Break Oriskany Break	Break } Decewville of Ontario Oriskany } Esopus Glenerie } Esopus Connelley Port Ewen	Grand Greve	Camden Break	Break Upper Hunton	Break
	Helderbergian	Break	Becraft New Scotland Kalkberg. Coeymans	Cape Bon Ami Saint Alban Break	Break Linden Break		Break

the Mississippian. Though considerable work has been done on these by Hall, Whitfield, and Walcott, they are not at all understood in the light of modern paleontology and stratigraphy. It may be said, however, that these western faunas are not of the same marine province as those of eastern America.

Late in the Middle Devonic the Arctic waters again spread southward, introducing a Euro-Asiatic assemblage of life into the Cordilleran sea. At the close of this epoch this fauna spread through the Dakota sea and connected with the Mississippi basin across Michigan, thus distributing the *Hypothyris cuboides* fauna into New York. Later in the Upper Devonic the *Spirifer hungerfordi* fauna is general from California to Iowa, and from Bisbee, Arizona, to Montana. To a limited degree it reaches the Mackenzie basin, and late in Upper Devonic time it extends to central New York. There is, however, another faunal element in the eastern region, best known in central New York, which, through many years of persistent collecting by Clarke, has grown to considerable proportions. This is the biota of the Portage, also known as the Intumescens fauna. In the entire western or Dakota sea there is nothing that can be directly compared with the Portage, while the goniatites and bivalves of the latter formation are in perfect agreement with those of western Germany. Not only has this fauna spread through the New Jersey straits, but also the *Spirifer disjunctus* fauna of the Chemung, both of which have decided Atlantic and European affinities.

The Portage sea deposited a black shale from New York to southwestern Illinois, but its waters did not communicate with the Gulf of Mexico. On the west side of the Cincinnati axis, the peculiar fauna is traceable as far south as Louisville and central Kentucky; farther south the sea appears to have been a practically lifeless one.

Throughout the Devonic, Appalachia was apparently a low lying land, which, however, was broadly elevated at the close of the Onondaga, as at this time an extensive foreland was added to this positive element. At the beginning of the Hamilton the foreland was largely re-submerged, and if Appalachia was again subjected to movement in this period it was in the southwestern portion, toward the end of Hamilton time, thus cutting off the intercommunication of the Gulf of Mexico with the Mississippian sea. The Acadian positive element, however, was distinctly lifted up, with folding that began late in Onondaga time and persisted throughout the Hamilton and Chemung. It was during this period of elevation that the rivers of this land transported the great masses of muds and sands now piled up in Maryland, eastern Pennsylvania, and New York, having a thickness in places of more than 10,000 feet. Similarly in Gaspé there are 7,000 feet of sandstones devoid of marine life, which elsewhere in Quebec contain Old Red fishes, the same types of fishes also occurring in New Brunswick and Nova Scotia. This Acadian highland, with its turbid rivers, continued well into Mississippian time.

Helderbergian.—In North America, during the Helderbergian, there were two distinct faunal provinces, an Atlantic and a Pacific. The latter is little known; it was first described by Walcott in his report on the Eureka district, Nevada, but was not distinguished as Helderbergian from the higher Devonic. There is little in this province to suggest the Bohemian, or even the eastern Russian Lower Devonic described by Tschernyschew. In southeastern Alaska, Kindle[162] has discovered Helderbergian faunas that clearly have Bohemian-Mediterranean connections, as shown in the abundance of *Hercynella.* It is probable that these Alaskan waters had direct connection with those of the Arctic ocean, for at capes Frazier and Leidy among other forms occur *Anoplotheca concava, Spirifer perlamellosus, Stropheodonta beckii* ?, and *Strophonella headleyana.* At cape Chidly, Labrador, Low has recently collected *Gypidula galeata* and the very diagnostic *Leptænisca concava.*

Helderbergian faunas are known in the Saint Lawrence trough on Gaspé peninsula; at Dalhousie, New Brunswick; northern Maine, and on Saint Helens island, opposite Montreal. The earliest of these faunas much remind one of those of the New York basin, but the higher elements on Gaspé and at Dalhousie pertain to a distinct subprovince. The *Spirifer macropleura* fauna does not seem to have penetrated beyond Square lake, Maine. These northeastern Lower Devonic faunas are described in detail by Clarke,[163] one volume having appeared in 1908, another in 1909.

In their typical development the Helderbergian faunas occur in the New York basin, and were described many years ago by James Hall. These faunas can be traced in the Appalachian trough as far south as central Virginia, and must have entered this basin by way of the New Jersey straits. The same fauna, but slightly changed, is again met with on the west side of the Cincinnati axis, first in southwestern Illinois and then across the Mississippi river in Missouri. In western Tennessee it is well developed as the Linden formation, and the identical fauna is again found in the Hunton deposits in the Arbuckle mountains of Oklahoma. This southwestern Helderbergian life of Gulf derivation practically coincides with that of New York, and both belong to the southern Poseidon realm, connecting with Bohemia and the Mediterranean.

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[162] Kindle: Journal of Geology, vol. 15, 1907.

[163] Clarke: Memoir no. 9, parts 1-2, New York State Museum, 1908, 1909.

Oriskanian.—In the eastern region of the Appalachian trough, from Maryland to southern New York, the Helderbergian appears to pass without break into the Oriskanian. The faunas are still of the southern Atlantic type and are unknown in other areas. Gradually they change into the typical Oriskany element, characterized by *Hipparionyx proximus, Spirifer murchisoni,* and *Rensselæria ovoides.* These pertain to a northern invasion, also well known in the Saint Lawrence sea at many localities. Clarke has termed it the Coblenzian invasion, because of its relationship to this northern European Lower Devonic series. While it is well developed in the Saint Lawrence trough, the best American development occurs in the Grand Greve limestone, where the longest sequence of Paleodevonic formations in America is found.

On the west side of the Cincinnati axis a very different late Oriskanian biota is preserved in the Camden, which extends from southwestern Illinois throughout western Tennessee. This, the Amphigenia fauna, has many characters in common with the Mæcuru of Brazil, and forms the introductory one to the later Onondaga.

In the Cordilleran sea Oriskanian faunas are unknown, though some deposits there are regarded as probably belonging to this time.

Erian.—In eastern North America there were two distinct subprovinces of the Middle Devonic that at different times were variously interblended. The Gulf invasion, first seen in the Camden of late Oriskanian time, continued unbroken into the Onondaga or Jeffersonville in southwestern Illinois. This was the southern element that introduced the widespread Devonic coral faunas, and as the invasion extended around the northern region of the Cincinnati axis, it blended with the other invasion from the North Atlantic. The latter represented the Oriskanian-Schoharie element, and together with the southern invasion furnished the later Onondaga or early Erian faunas that spread as far north as James basin. West of the Indiana basin there are no deposits of this time except in the Great Basin of Nevada. Walcott has described the latter in his volume on the Eureka district, but the species need revision to accord with present knowledge. To the writer, the Great Basin and the Mississippian sea appear to have almost nothing in common.

Before the close of the Onondaga the intercommunication between the New York basin and the Saint Lawrence sea was permanently destroyed. Subsequently the Appalachian sea intermittently received migrations from the middle Atlantic through the New Jersey straits. These additions are most noticeable during the Hamilton, Tully, Ithaca, and Chemung. Every now and then the *Tropidoleptus carinatus* fauna of the Atlantic swarmed into this trough, but did not make much progress in the Mississippian sea. Here the Gulf faunas persisted in considerable purity, and migrated around the Cincinnati axis into the western part of the New York basin. New York state preserves the best record of these eastern or Atlantic forms and the southwestern or Gulf waves of migrants. Some of the characteristic species of the New York Hamilton, however, appear somewhat earlier in the Jeffersonville limestone of the Indiana basin.

In the Cordilleran and Dakotan seas there is no evidence of Middle Devonic faunas until near the close of this epoch. In the Manitoba region then occurs the *Stringocephalus burtini* fauna in the Winnipegosan series, which in Europe is found toward the end of the Middle Devonic. The same brachiopod is also found in southern Minnesota, in red residual clay or geest. In Iowa the lower Wapsipinicon may belong to this time, yet its fauna, though meager, seems to be rather of the early Upper Devonic type.

Neodevonic.—Toward the end of the Middle Devonic the Gulf embayment became closed, and about this time there appeared in Iowa a western fauna, that of the Cordilleran sea, which spread to the Kankakee axis and through the Iowa and Traverse basins, connecting with the Mississippian sea. However, it does not yet appear that much of this western life invaded the eastern sea at any time during the Erian, Senecan, or Chautauquan. Clarke thinks that the strange and decidedly European Portage or Intumescens fauna migrated from the Cordilleran sea into the New York basin, but to the writer its path seems to have been from the Atlantic through the New Jersey strait. These forms may have distributed themselves along the Atlantic shore of Appalachia into the Appalachian trough, thence south to the shallow region of Virginia, then across to the eastern shore of Alleghania, and so north into western New York. If this path is not admitted to be the true one, the reverse must have taken place, in which event the *Intumescens* goniatites came to New York from the Cordilleran sea, developed in great generic and specific variety in the western New York basin, and then migrated into the Atlantic and across to Europe. It is hardly probable that the same genera developed twice from the same primitive stock, both in New York and western Europe.

The Appalachian trough served as the means of continuing the Atlantic Hamilton faunas into the Ithaca and Chemung, and throughout this time the New Jersey straits were open. In the northeastern end of the trough the normal marine conditions gave way to vast estuarine flats of red muds, while the Ohio and Indiana basins had mainly changed to black seas, owing to the cul-de-sac condition of this area. For these reasons the

Neodevonic faunas of eastern America are varied, and are not nearly so uniform in composition as those of the Hamilton.

In the Cordilleran sea within the area of the United States, from Arizona (Martin and Lower Globe formations) and California (Kennett formation) east to Iowa, occurs the Lime creek or *Spirifer hungerfordi* fauna, clearly of Euro-Asiatic derivation. In the Manitoba region, Tyrrell has collected and Whiteaves has described a late Mesodevonic fauna characterized by the well known European *Stringocephalus burtini.* It is their Winnipegosan biota, together with Neodevonic forms, as *Gypidula comis, Pugnus pugnus,* and *Stropheodonta interstrialis.* This dolomite, 100 feet in depth, is followed by the Manitoban limestone and shale (with brine springs), 200 feet in thickness, apparently equivalent to the Lime creek of Iowa. The Manitoban fauna is widespread in Alberta, Athabasca, Mackenzie, and Yukon regions, extending to the Arctic ocean. It was first described by Meek, and has since been revised by Whiteaves. In these northern areas some salt and more gypsum are present.

Another late Devonic fauna with a peculiar and distinct aspect is that of the Lower Ouray of Colorado, described by Girty, and very recently by Kindle.

The youngest of the western Devonic horizons appears to be the Three Forks shale of Montana, described by Peale. The lower 70 feet of shale and argillaceous limestone have no fossils, but are followed by about 30 feet of green, black, and argillaceous shales crowded with Upper Devonic fossils, of which *Spirifer whitneyi* is the most common. Recently Raymond[164] has described the faunule from the lower beds of the upper Three Forks shale, of which the following are the more characteristic forms: *Camarotœchia contracta, Leiorhynchus mesacostale, Spirifer pinonensis, Cleiothyridina devonica, Locopteria holzapfeli, Platyclymenia americana, P. polypleura, Prolobites simplex, Tornoceras crebsiseptum,* and *T. douglassi.* At the top of the Three Forks, and beneath the Madison, occurs a "yellow laminated sandstone 25 feet thick" (Peale), having a very different fauna. This was shown the writer by Raymond. Among the fossils *Syringothyris carteri* and *Spirifer* cf. *striatus* are prominent. This faunule is to be compared with that of the lower Louisiana limestone of Pike county, Missouri. Therefore there is here, as in the Mississippi valley, a break in deposition clearly distinguishing the Devonic, both physically and faunally, from the Mississippic.

The Alaskan Devonic has been described by Kindle.[165]

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[164] Raymond: American Journal of Science, vol. 23, 1907. Annals of the Carnegie Museum, vol. 5, 1909.

[165] Kindle: Bull. Geological Society of America, vol. 19, 1908. Journal of Geology, vol. 15, 1907.

Mississippic Period (new emendation)[166]

(Lower Mississippian or Kinderhook and Osage of geologists)

See plates 78-80, and pages 494, 495

The extensive inundation of the Middle Devonic was maintained to the early Upper Devonic, and was followed by an emergence of seemingly small extent. The retreat of this water was most marked in the region along the eastern side and the northern part of the Cordilleran sea, where it may have represented as much as 10 per cent of the previous inundation, but in the United States it does not appear to have been greater than from 5 to 9 per cent. In other words, the Devonic was not closed by a very decided emergence, as was the case in most of the previous periods. For this reason the faunal changes in the Cordilleran sea are thought to have appeared slowly, and were not of a marked character. In the area of the eastern United States, however, the physical changes were far more decided, owing to the filling up of the northeastern marine basins toward the close of the Devonic and the local emergence in progress in that region.

Toward the close of the Keokuk the period terminated by considerable emergence in all the seas, but more especially in the Cordilleran sea, which appears to have been completely blotted out toward the end of the Mississippic. At a few localities in Montana faunas of supposed Saint Louis or Meramec time have been reported, but according to Ulrich some of the fossils are clearly of the Pottsville. These faunas can now be duplicated in Arkansas from horizons of early Pottsville age.

Mississippian sea.—In the southern part of the Mississippian sea of late Devonic time the Chemung emergence was continued into the Kinderhookian epoch. The new or Fern Glen transgression from the Gulf of Mexico began to appear as early as the Bradfordian, depositing the Chattanooga black shale with almost no organic remains. This invasion spread north along the Mississippi valley east of Missouria and west of the Cincinnati axis, as far as southern Indiana. This is the southern Kinderhookian of Weller. Finally, late in the Kinderhookian (Fern

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[166] The more useful references to the literature on the Kinderhook faunas and formations are the following:

Weller: Transactions of the Academy of Sciences, Saint Louis, 1899, 1900, 1901, 1905, and 1906. Journal of Geology, 1898, 1901, 1905, and 1909. Iowa Geological Survey, vol. x, 1900.

Bassler: Smithsonian Miscellaneous Collections, Quarterly, no. 1814, 1908.

Prosser: Journal of Geology, 1901 and 1902. American Geologist, 1904.

Girty: Monograph XXXII, part ii, U. S. Geological Survey, 1899. Professional Paper no. 16, U. S. Geological Survey, 1903. Proceedings of the Washington Academy of Sciences, 1905.

Rowley: Missouri Bureau of Geology and Mines, vol. viii, 1908.

Stevenson: Bull. Geological Society of America, vol. 14, 1903.

Table of Mississippic Formations

Series	Missouri west of Missouria; also northern Arkansas	Missouri east of Missouria; also western Kentucky and Illinois	Iowa	West of Cincinnati axis, Kentucky and Indiana	East of Cincinnati axis, Ohio and Pennsylvania
Osagian	Break	Break	Break	Break	Break
	Boone (Fort Payne of southern Appalachian sea. Tullahoma of western Kentucky	Warsaw (part)			
		Keokuk	Keokuk	Knobstone: Harrodsburg	Logan (Shenango shale of Pennsylvania)
		Upper Burlington	Upper Burlington	New Providence	Pocono: Black Hand (Shenango of Pennsylvania)
		Lower Burlington	Lower Burlington		Upper Cuyahoga (Meadville of Pennsylvania)
Kinderhookian	Choteau: Pierson (Saint Joe)	Fern Glen	Upper Kinderhookian: Leptopora, or zone 7	Rockford	Middle Cuyahoga (Sharpsville of Pennsylvania)
	Northview (Saint Joe)	Hannibal	Oolite, or zone 6	Upper New Albany	
	Sac	Louisiana	Le Grand: Upper yellow sandstone, or zone 5	Chattanooga of Tennessee	Lower Cuyahoga (Orangville of Pennsylvania) Sunbury
	Noel (= Eureka)	Bushberg	Louisiana, or zone 4 Limestone and oolite, or zone 3		Berea (Cussewago and Corry of Pennsylvania)
	Break	Break	Chonopectus, or zone 2 = Typical Kinderhook of Illinois = English River of Iowa Blue clay, or zone 1		Bedford — Bradfordian of Pa. and N. Y.: Knapp Oswayo
		Glen Park	? Break	Break	Cleveland — Cattaraugus
		Break			

Glen), the Mississippian sea united across the Kankakee axis with the northern Appalachian waters and the eastern extension of the Cordilleran sea. The faunas of the southern area were derived from the Gulf of Mexico, which retained many of the descendants of the previous Hamilton fauna. Other forms are also in harmony with those of western Europe.

Toward the close of the Kinderhookian the three provinces, formerly separated, were united, and the Mississippian sea became more general. Weller states:

> "With the submergence of the Kankakee Peninsula and the partial or complete submergence of the Ozark land, the source of the clastic sediments in the immediate Mississippi Valley was removed, and a great period of limestone formation was initiated which is best exemplified in the Burlington and Keokuk formations. The fauna of this clear sea was in large part an outgrowth of the later Kinderhook faunas, and is best characterized by the wonderfully rich [and indigenous] crinoidal element" (1909, 275).

The Rockford formation has a fauna of Gulf origin and is marked by the goniatites *Prodromites præmaturus, Prolecanites greeni, P. lyoni, Aganides rotatorius, Muensteroceras oweni,* and *M. parallelum.* In the Choteau, the following goniatites are also of southern origin: *Prodromites gorbyi, P. ornatus, Prolecanites gurleyi, Pericyclus blairi, Aganides discoidalis, A. jessieæ,* and *Muensteroceras osagense.*

The Osagian epoch followed the Kinderhookian, and introduced the widespread Burlington limestone, replete with Echinodermata. In the Paleozoic, starfishes are always rare, and they are so here, but the echinoids and blastoids are more common. The crinoids, however, are abundant and highly differentiated, nearly 400 species being known from the Burlington alone, most of which are found in the vicinity of Burlington, Iowa. This crinoidal assemblage is here indigenous, this being an area prolific in generating crinoids, but in free communication with the Gulf of Mexico and western Europe. "Every genus in the Mountain Limestone occurs also in the American faunas . . . ; furthermore, all of those genera which occur in both this Mississippian province and in Europe are represented by a larger number of species in America" (Weller, 1909, 276). The connection is with the Atlantic and western Europe—England and Ireland—but especially with the Tournacien series of Belgium, the fauna of which is nearly all derived from the large quarries in the vicinity of Tournai.

Above the Burlington is the Keokuk limestone, which in the north and east is more clastic, and often with much shale, but in the south the clear water seas continued, introducing a horde of sharks, as shown by the teeth of these fishes, which are here far more numerous than at any other geologic age. About 400 species are known in the American "Lower Carboniferous" and about 200 in Europe, most of which occur in the Mississippic.

Appalachian basin.—In the northern Appalachian basin the Chemung sea continued apparently without break into the Bradfordian, and for a time maintained connection with the Atlantic by way of the New Jersey straits. After the Bradfordian this opening was permanently destroyed. It is probable that the brachiopods *Chonopectus* and *Paraphorhynchus* are of North Atlantic origin, for they occur in the Bradfordian at Warren, Pennsylvania; later they migrated to Iowa, and there became dominant in the earlier portion of the Upper Kinderhookian. In late Kinderhookian time, therefore, the Mississippian sea had these earlier and independent faunas variously commingled.

The Waverly series of the northern Appalachian basin is a continuous one from the Chemung to the close of the Mississippic. Above the Bradfordian it begins in clastic materials composed of shales, sandstones, and some conglomerates. The faunas are as yet imperfectly known. As Girty has given much time to the collection and study of these forms, his correlations are here followed, and are given in the table of formations in the column "East of Cincinnati axis" (1905, 5-7). The Marshall series in Michigan is also representative of this basin and directly associated with the Waverly series, but no attempt has been made to correlate the various beds. It is probable that a part of the Catskill series is likewise of Bradfordian time. In the main these are continental deposits, but they may have zones of estuarine sediments. The Pocono is also Mississippic in time, and its deposits, which are chiefly continental with coal beds, may begin as early as the Bradfordian.

Cordilleran sea.—The Pacific and Arctic faunas are widespread in the Cordilleran sea. The one best known is the *Spirifer centronatus* fauna of the Pacific realm in the Madison limestone, which extends to Missouri in the Choteau of Kinderhookian time. In the Yellowstone Park region it persists with little change in the western Cordilleran sea through 1,600 feet of limestones. According to Girty, the Madison occupies the entire time of the Mississippic period as here defined—that is, to the close of the Keokuk. Weller (1909, 282) states that "this fauna shows many affinities with the southern Kinderhook faunas of the Mississippi valley"—that is, the Choteau. Girty (1899) reports that 37 per cent of the Madison fauna is common to the two regions. It seems, however, that this intercommunication ceased at the close of the Kinderhookian, as nothing is known of the wonderful Burlington crinoid fauna in the western sea. The life of Lake valley, New Mexico, is now held to be older, and Weller regards it "as a close ally of the fauna of the Fern Glen." The Madison limestone fauna is known from southern Arizona north to southern British Columbia. Further north the Banff limestone has Mississippic faunas. To the late Kinderhookian of the Cordilleran sea the writer refers also the Upper Ouray, Leadville, and Millsap limestones of Colorado. The lower part of the Red Wall of the Grand Canyon and the Escabrosa and Modoc of Arizona likewise belong here.

During the late Devonic the eastern extension of the Cordilleran sea appears to have become land for a time, and this area in Iowa and Missouri probably continued into the earliest Bradfordian. The western sea then again extended across Iowa and united with the northern Appalachian basin during the time of the Chonopectus zone of the Burlington section. This northern Kinderhookian sea remained unconnected with the Mississippian sea across Kankakeia until toward the close of the Kinderhookian. In the meantime the eastern extension of the Cordilleran sea was encroaching upon the western side of Missouria, and made connection to the south of this land at an earlier date than across the Kankakee axis.

Saint Lawrence sea.—In Nova Scotia, New Brunswick, and Newfoundland occurs the very thick Windsor series of variegated marls, sandstones, and dolomites, followed below by beds of gypsum, marls, sandstones, and shales. The oldest fauna of this series at Windsor includes but few species, and these remind one of Kinderhookian time. In the higher dolomites at Windsor a rich fauna appears that is very different from that in any American Mississippic horizon, and as it is also unlike those of Europe, it is difficult to correlate. Seemingly it is of Keokuk time, yet may be somewhat younger, as *Lithostrotion* is reported at Pictou, which is not far from Windsor.

According to Dawson, the Horton series, consisting of coarse continental deposits, follows below. The plants of this series and of the Albertite beds are regarded by D. White as of late Kinderhookian time. The Bonaventure of the Gaspé peninsula is also of Mississippic time, and consists largely of conglomerates and sandstones, red in color and all continental in character.

Arctic regions.—In Alaska, on the Porcupine, near the International boundary, Kindle reports Mississippic shales holding a small fauna which Girty believes to suggest "the earliest fauna of the Mississippian." The few associated plants are regarded by D. White as probably indicative of Kinderhookian time. Brooks and Kindle state that there may be no break here between the Devonic and the Mississippic.

In the Arctic archipelago there is no clear evidence of Mississippic faunas, yet on Feilden peninsula (latitude 82 degrees 43 minutes) species are cited suggestive of this time. The evidence for the Tennesseic and Pennsylvanic is much stronger.

According to D. White, the plants of the lower coal beds about cape Lisburne, Arctic Alaska, indicate the Mississippic and of a time "slightly younger than the Ursa flora." Above is a marine series with corals, rather suggestive of the early Pennsylvanic.

Tennesseic Period (new: Ulrich)

(Upper Mississippian or Saint Louis and Chester of geologists)

See plates 81, 82, and pages 495, 496

The emergence at the close of the Mississippic blotted out the Cordilleran sea of wide extent, and no deposits of Tennesseic age are as yet definitely known here except possibly in the Arctic region. The Baird or *Productus giganteus* fauna is referred to the Pennsylvanic. The best known area of Tennesseic sediments is that of the Mississippian sea, where the greatest thickness is apparently not in excess of 1,200 feet. It is probable that in no part of the latter sea did its waters persist from the Mississippic into the Tennesseic, yet apparently the Keokuk emergence was of very short duration. With the introduction of the Saint Louis transgression much change in the life took place. The crinoids no longer are present in vast numbers and species; the echinoids (*Melonites*) are much larger and dominate the Meramecian; *Pentremites* was previously of rather rare occurrence, but now becomes more abundant and larger and is one of the dominant types of invertebrates, especially in the Chesterian; the Bryozoa of the family Fenestellidæ, having thickened supporting parts, as *Archimedes* and *Lyropora,* are prolific in numbers and species, especially in the Chesterian. Of brachiopods, *Cleiothyridina, Eumetria,* and *Dielasma* are dominant, large spirifers like *S. logani* are absent, while *Athyris, Camarophoria, Chonetes,* and *Syringothyris* are rare or wanting. Among the corals, *Lithostrotion,* or rather, *Axinura,* apparently originates here; certainly those with large corallites begin at this time and are dominant in the Meramecian.

The emergence terminating the Tennesseic was a complete one in the area of the Mississippian and Appalachian seas, while that of the Cordilleran sea was absent throughout this period. In the Oklahoma basin, however, the Chesterian sea may have continued unbroken into the Pottsvillian. It also seems to be true that the seas of Pennsylvanic time appeared somewhat earlier in the Cordilleran and Californian than in the

Table of Tennesseic Formations

Series	Mississippi valley east of Missouria. Western Kentucky. Ulrich		West of Cincinnati axis, Indiana	East of Cincinnati axis, Ohio	South of Missouria. Northern Arkansas	Appalachian area		Iowa
						Northern area	Southern area	
Chesterian	Break				Break	Break		
	Birdsville	Kaskaskia 600–880 feet	Birdsville (= Huron)		Pitkin	Mauch Chunk	Pennington	
	Tribune		Break	Break	Fayetteville			
	Cypress			Maxville limestone	Batesville	Greenbrier		
				Break	Break	Break		Pella Verdi
	Ohara	St. Genevieve 140–245 feet (Princeton)						
	Rosiclare							
	Fredonia		Break					Springvale
Meramecian	Saint Louis, 300 + feet		Mitchell				Newman	Break
	Spergen, up to 100 feet. (Includes upper beds of the Warsaw of Hall. See Weller, 1907)		Spergen (= Salem, Bedford), 5–100 feet					
	Break		Break					

two eastern seas. In the Saint Lawrence sea there is almost no evidence for the presence of Meramecian deposits and none at all for the Chesterian.

Mississippian sea.—The best general account of the successive sediments of this sea in the area of its longest development—that is, western Kentucky and southwestern Illinois—is that of Ulrich.[167] This succession is given in the column "Mississippi valley east of Missouria," in the table of formations belonging to this period.

The Upper Warsaw[168] (= Salem or Spergen), a rather limited formation, introduces the Meramecian, and many of its fossils are continued into the higher horizons. Hall described the fauna in 1858,[169] the more characteristic forms being *Zaphrentis spinulifera, Archimedes wortheni, Pentremites koninckiana, Spirifer subcardiiformis, S. lateralis, S. subequalis,* and *Bellerophon sublævis.*

The Spergen oolitic limestone is noted for its dwarfed fauna, preserved in oolites. It was first described by Hall; later by Whitfield.[170] The earliest appearance of this fauna was in the Upper Warsaw; it became typical and enlarged in the Spergen; its third occurrence was in the Fredonia (35 species of the second occurrence are here represented), and for the fourth time it appeared in the Tribune (40 of the 70 original species are present). Ulrich has recently discovered the same fauna, greatly diminished, in the Pottsville, and its existence in the Montana-Idaho region, described by Meek, should probably be attributed to the same age.

The Saint Louis limestone is usually heavy bedded and gray, with much siliceous matter that is liberated as chert. The guide fossils are *Lithostrotion* (?) *canadense* and *L.* (?) *proliferum.* Ulrich states that the columella of these forms is not styliform, as in *Lithostrotion,* and that the species are more nearly allied to *Lonsdaleia.* Castelnau was the first to describe these corals. His *Astræa mamillaris* is identified as Fischer's species, and was obtained on the Ohio river, in the state of Illinois. This is the form that is usually known as *Lithostrotion canadense.* Castelnau's *Axinura canadensis* is the form now called *L. proliferum;* it was collected on the shore of lake Saint Claire, Michigan, this fact leading him to call it *canadensis.* Both of these corals are figured and described by Rominger, who reports them as occurring at Wildfowl bay, Bellevue, and Grand Rapids, Michigan. Under these circumstances the coral now called *L. proliferum* will in future have to be known as

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[167] Ulrich: Professional Paper no. 36, U. S. Geological Survey, 1905.

[168] Weller: Bull. 8, Illinois Geological Survey, 1907, p. 83.

[169] Hall: Geological Survey of Iowa, Paleontology, part ii.

[170] Whitfield: Bull. American Museum of Natural History, 1882; republished and extended by Hall in Indiana Geological and Natural History Survey, 1882.

Axinura canadensis (it is the genotype of Castelnau's new genus *Axinura* and is the only species referred to it), and the *L. canadensis* of authors must become *Axinura mamillaris* Castelnau (not Fischer). Should the two forms eventually be regarded as one species, the name would then become *Axinura canadensis.*

Other Saint Louis guide fossils are *Melonites, Archæocidaris wortheni, Pentremites conoideus, P. cavus, Dichocrinus simplex, Cystodictya major, Spirifer keokuk littoni,* and *Eumetria verneuiliana.*

The Saint Genevieve is marked by *Michelinia subramosa, Cystelasma rugosum, Lithostrotion harmodites, Amplexus geniculatus, Pentremites florealis, Platycrinus huntsvillæ,* and *Pugnax ottumwa.* Ulrich gives many other species (1905, 47, 48), but all have a longer range than the Saint Genevieve. According to Weller, the latter was the time of greatest transgression.

The Kaskaskia is the chief fossil horizon of the Chesterian. It is marked by *Pentremites godoni* and *P. pyriformis* (also occurs below), *P. obesus, P. forbesi,* and *P. pyramidatus* (above), *Agassizocrinus, Pterotocrinus* (above), many *Archimedes, Lyropora, Meekopora, Prismopora serrulata, Spirifer increbescens, Spiriferina spinosa, Cleiothyridina royssi, Composita subquadrata,* and *Eumetria vera.*

As ammonites generally serve as good guide fossils to horizons, it is deemed advisable to give the species found in the Batesville: *Goniatites sphæricus* and *G. striatus* (both are European forms). In the following shales, the Fayetteville, occur *Bactrites carbonarius, Glyphioceras calyx, Goniatites crenistria, G. newsomi, G. subcircularis,* and *Gastrioceras entogonum.*[171]

Arctic region.—In the Arctic archipelago *Lithostrotion* has been identified in at least three localities. The associated species, however, do not make it clear whether the horizon is Tennesseic or Pennsylvanic. Coal beds, possibly of early Tennesseic age, occur in many places in the Arctic archipelago and more certainly at cape Lisburne, Arctic Alaska. It is more probable that these faunas are of Pottsvillian age.

Pennsylvanic–Permic Period

See plates 83-85, and pages 496-498

In North America the Permic was not introduced with a new submergence, as was the case in Europe and India; on the contrary, the Pennsylvanic transgression attained its maximum spread late in this period, after which there was continuous emergence until the close of the Permic. In other words, in America these periods belonged to one diastrophic cycle. Each part of these movements was of very long duration. From the standpoint of marine invertrebrates, the life of the Permic period—that is, the Permic in the widest sense—was normally developed only in the Trans-Pecos region of Texas. Elsewhere the early Permic waters (Oklahomian) were not normally marine, and therefore retained the hardy Pennsylvanic species, especially the bivalves. Associated with these, however, were a few forms of ammonites, indicative of early Permic types (Artinsk, as this term is now used in the wider sense by most stratigraphers). This was particularly true of the region east of the Mississippi river, while to the west of this stream the Pennsylvanic waters were more often normally marine, followed in early Permic time by an abnormal sea that deposited over great areas red muds replete with gypsum, some salt, and, locally, dolomites. In the Rocky Mountain area, however, the seas were more normally marine in the Pottsvillian, and in the early Missourian local elevation and shoaling began, with much accumulation of sands. Later this uplift prevented the eastern waters from mixing with those of the Pacific, thus causing the latest Missourian faunas to become very different from those of the Mississippi valley.

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[171] Smith: Monograph 42, U. S. Geological Survey, 1903.

Saint Lawrence sea.—In the maritime provinces of eastern Canada the Pennsylvanic is well developed and usually of very great thickness. The celebrated Joggins section of Nova Scotia is 13,000 feet in depth, and may extend into the Permic. The Cape Breton series is 10,000 feet thick, and the Pictou field has a similar thickness. The Riversdale and Harrington river beds and the plant-bearing beds near Saint Johns, New Brunswick, are also of Pennsylvanic age.

It is very rare that marine fossils are reported from this region, and the few that have been listed indicate Pottsvillian rather than Missourian time. In the Riversdale has been found *Belinurus grandævus,* and Ami has shown the writer examples of *Euphemus carbonarius* and *Leaia* from the same beds.[172]

Pottsvillian or Lower Pennsylvanic.—There is no system of Paleozoic formations in America in so unsatisfactory a condition for detailed correlation as the Pennsylvanic. Probably no other system has received so much attention, and yet on the basis of marine invertebrates the faunal characteristics distinguishing the Pottsvillian from the Missourian are still undetermined. It is true that marine life is not generally present in these lower formations; the literature, however, indicates that such forms have been seen at many localities, but the species are very rarely men-

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[172] Ami: Annual Report of the Geological Survey of Canada, vol. 12, 1899, pp. 100A–204A.

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Series	C
Permic	
	Oklahomian or Permo-Carbonic
Pennsylvanic	Missourian
	Pottsvillian

Table of Pennsylvanic-Permic Formations

Series		Central Appalachian. West Virginia, etcetera		Northern Appalachian. Bituminous. Pennsylvania–Ohio	Anthracite region, Eastern Pennsylvania	Indiana	Illinois	Iowa and Missouri	Kansas (numbers refer to the zones of Adams)	Northeastern Oklahoma	Central Texas	Trans-Pecos, Texas
Permic									Break	Break	Break	Break Rustler Castile gypsum
	Oklahomian or Permo-Carbonic	Absent		Break Dunkard or Upper Barren	Absent	Absent	Absent	Absent	Oklahomian: Cimarron { Kiger Salt Fork Big Blue { Sumer (Marion) } (40–47) Chase } Wreford	Oklahomian: Quartermaster Greer. Much gypsum Woodward (Whitehorse) Blaine } Much Enid, 1,500 feet } gypsum	Brazos: Double Mountain Clear Fork Wichita (Albany)	Guadalupian: Capitan limestone, 1,800 feet Delaware Mountain, 1,500 feet
Pennsylvanic	Missourian		Coal Measures	Monongahela or Upper Productive Coal Measures	Anthracite. Coals A, B, C,	Break	Break	(Top. Cottonwood)	Council Grove (38, 39) { Neosho Cottonwood		Cisco	Hueconian: Hueco limestone, 3,000–5,000 feet
		Braxton		Conemaugh or Lower Barren Ames limestone, near middle		Upper or Barren Coal Measures		Missouri series	Wabaunsee (29–37) Shawnee (22–28) Douglas (19–21) Pottawatomie (10–18) Marmaton (2–9)	Chandler Hominy	Canyon	Break
		Charleston		Allegheny or Lower Coal Measures { Freeport Kittanning Clarion	Coal D	Lower Coal Measures	Coal, No. 6 Coal, No. 2 (? Morris)	Base, Winterset of Iowa and Bethany of Missouri	Cherokee (1)	Marmaton Cherokee	Strawn Break	
		Kanawha	Pottsville	Homewood Mercer Conoquenessing Sharon	Upper Transition series			Des Moines series Break	Break		Milsap Bend Break	Absent
	Pottsvillian	Nuttall Sewell Raleigh Quinnimont Clark Pocahontas			Upper Lykins Lower Transition Lower Lykins Break	Mansfield ? Break	Coal, No. 1 ? Break					

tioned. The correlations thus far made are based on stratigraphy, ratified by the excellent floral knowledge of David White, which has been published in a number of papers. The map of Upper Pottsville time is chiefly founded on the evidence furnished by the flora and on certain correlations made by Girty. He states:[173]

> "The Pottsville group has a distinct fauna and appreciable changes occur in the later Pennsylvanian. But the changes are by no means so marked as one would be led to expect from the thickness of the strata involved, the extent of the territory they cover, and the varying conditions of the time and the place."

In the Appalachian region, Girty[174] states that

> "The Pottsville series is righly fossiliferous in the way of fossil plants, but furnishes as a rule few invertebrates. The invertebrate faunas are, except in a few instances, peculiar and restricted, and clearly indicate unusual environmental conditions. The most frequent fossil is *Naiadites elongatus* Dawson, with which are associated bivalve crustaceans, such as *Estheria*, *Leaia*, and Ostracods [also *Spirorbis*]; while more rarely fragments of *Prestwichia*, or Limuloids, or fish scales and plates are brought to view. An occasional Pectinoid, almost always of the type of *Arviculopecten whitei*, together, not infrequently, with *Lingula* and *Orbiculoidea*, indicates that these faunas cannot be considered as owing their peculiar facies to strictly fresh-water conditions."

In Arkansas the Pottsvillian series begins with the Morrow, which, according to D. White, has a flora "of latest or earliest Upper Pottsville age." In the upper part of the Morrow is the Kessler limestone, beneath which is the shale with the Pottsville flora, followed by the Brentwood or Pentremital limestone. The fauna is largely new, but some of the old species are: *Pentremites rusticus, Spiriferina transversa, Hustedia,* and *Squamularia*. "Few paleontologists will at first be willing to accept *Pentremites* as ranging above the top of the sub-Carboniferous, but the evidence at hand leaves no other conclusion tenable" (Girty, 1905, 9).

In the far West occur other pentremite faunas usually regarded as of late "Mississippic" age. These were collected by the Hayden survey and listed by Meek.[175] One lot is from "Old Baldy," near Virginia City, Montana, and among other forms includes *Pentremites symmetricus, P. godoni ?, Schizophoria resupinata, Composita subtilita, Dielasma bovidens ?, Astartella newberryi ?, Trepospira sphærulata,* etcetera. In the light of the Arkansas collections these fossils must now be referred to the Pottsvillian. At another place on the "Divide between Ross fork and Lincoln valley, Montana," is found a different fauna, according to Meek having, among others, *Cyathophyllum subcæspitosum, Lophophyllum, Pentremites bradleyi, P. conoideus, P. godoni ?, P. subconoideus, Productus longispinus, P. semireticulatus, Eumetria verneuiliana, Spirifer rockymontanus, Dielasma turgidum, Nucula shumardii, Cypricardinia indianensis, Conocardium meekianum ?, Euomphalus spergensis,* etcetera. "Some seven or eight of the thirty-two or thirty-three species thus found seem to be in all respects, so far as the specimens afford the means of comparison, identical with forms occurring at the celebrated Spergen Hill locality"; and the others "belong to genera found at that locality, and so closely resemble [that fauna] in their small size and other characters that they may be regarded as representative forms." Meek looked upon the horizon "as representing the Saint Louis limestone" (433, 434). The presence of *Productus longispinus* and the corals denotes forms unknown in the Spergen fauna, and it is probable that this dwarf biota represents a holdover into Pottsvillian time, being presumably of the same horizon as that at Old Baldy. Moreover, Ulrich has shown that this dwarf fauna recurs at four different levels in the Tenneseic, and he has recently informed the writer that a further recurrence has been discovered in the Pottsvillian of Missouri. The Old Baldy locality he believes to be contemporaneous with the Arkansas Morrow formation, which he regards as of early Pottsvillian time.[176]

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[173] Girty: Journal of Geology, vol. 17, 1909, p. 309.

[174] Girty: Proceedings of the Washington Academy of Sciences, vol. 7, 1905, p. 8.

[175] Meek: Sixth Annual Report of the U. S. Geological Survey of the Territories for 1872, 1873.

Since the above was written, the writer was shown by Raymond collections made by him in the vicinity of Old Baldy, Montana. From the lower beds he has *Petremites* large, near *P. obesus,* and *P. fohesi, Productus* cf. *fasciculatus, Rhynchonella* (?) *metallica, Composita subquadrata, Cleiothyridina roysii, Eumetria verneuiliana, Dielasma turgidum,* etcetera. From higher strata *Syringopora multattenuata, Michelinia, Productus* cf. *fasciculatus, P. nebrascensis, Orthotetes robusta* (small), *Pugnax rockymontana, Spirifer* near *camerata,* and Hall and Whitfield's *S. striatus, Spiriferina spinosa, Hustedia mormoni, Eumetria vera, Composita subquadrata, Cleiothyridina orbicularis,* etcetera. Near the top of the formation occur *Productus costatus, P. semireticulatus, P. punctatus,* and *Composita subtilita.* These faunules, therefore, bear out the conclusion that they represent the time of the Morrow of Arkansas or the earliest Pottsvillian.

In regard to the Pottsville Girty states:

> "From its faunal side it is of little interest in the way of correlation in the Central and Eastern States. It will, however, probably establish some interesting relations between beds of the West and the Southwest. The Pennsylvanian

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[176] Ulrich: Professional Paper no. 24, U. S. Geological Survey, 1904, p. 111.

faunas of the West have often a facies which is novel and perplexing to one familiar only with the well known Eastern ones; and it is probable that the lowest faunas of this region will in many cases prove to be of Pottsville age. . . . The resemblances to the fauna of the Morrow formation . . . are sufficiently numerous and striking to make this a very promising hypothesis.

"It will be remembered that C. D. Walcott described an interesting fauna from the Eureka district, in which there was found a commingling of Upper and Lower Carboniferous types. This is likely to prove of Pottsville age. The lowest Pennsylvanian faunas of Colorado and of New Mexico, especially the latter, also show similarities which appear to me highly significant. The Bend and Milsap formations of Texas may likewise prove to be Pottsville" (Girty, 1905: 10).

The following are some of the more characteristic fossils of the Pottsvillian (A = Appalachian region, W = Southwestern and Western, no letter = both regions): *Triticites secalicus, Lophophyllum sauridens* (W), *Cystodictya carbonaria* (A), *Rhipidomella pecosi* (W), *Chonetes mesolobus, C. platynota* (W), *Pugnax rockymontana* (W), *Productus longispinus, P. muricatus, P. nebrascensis, Spirifer cameratus, S. rockymontana, Spiriferina kentuckyensis* (W), *Hustedia mormoni* (W), *Cleiothyridina roisii* (W), *Composita subtilita, Squamularia perplexa* (W), *Dielasma millepunctata* (W), *Aviculopecten occidentalis* (W), *A. coxanus, A. hertzeri* (A), *A. whitei* (W), *A. interlineatus* (A), *Pinna peracuta, Aviculopinna americana* (A), *Astartella vera, A. varica* (A), *Macrodon obsoletus, M. carbonarius, M. tenuistriatus* (A), *Schizodus subcircularis, S. affinis, Lima retifera, Bellerophon percarinatus* (A), *Patellostium nodocostatum* (W), *Euphemus nodocarinatus* (A), *E. carbonarius* (A), *Stearoceras gibbosum* (W).

In the Bend of Texas occur *Goniatites striatus, G. crenistria* (both occur lower in shales correlated by J. P. Smith with the Batesville or Fayetteville of Arkansas), *Gastrioceras entogonum* (also in Fayetteville), *G. compressum, Paralegoceras iowense* (also in "Coal Measures" of Iowa), *P. texanum, Metacoceras walcotti,* and *Stearoceras gibbosum.*[177] According to Cummins,[178] there are also included *Hadrophyllum aplatus, Chonetes mesolobus, Productus nebrascensis, Spirifer cameratus, Myalina subquadrata, Euphemus carbonarius,* etcetera. Ulrich[179] likewise regards the Bend as of early Pottsvillian time.

According to paleobotanical evidence the Pottsvillian, together with the Allegheny, "approximately represents the Westphalian or Muscovian" of Europe. "The Westphalian is the period of *Cheilanthites, Mariopteris,*

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[177] Smith: Monograph 42, U. S. Geological Survey, 1903.

[178] Cummins: Second Annual Report of the Geological Survey of Texas, 1891, p. 366.

[179] Ulrich: Professional Paper no. 24, U. S. Geological Survey, 1904, p. 111.

Diplothema, Crossotheca, Eremopteris, Palanopteris, Lonchopteris, Megalopteris, Lesleya, Neriopteris, Bothodendron, Ulodendron, Lepidophoros, and *Whittleseya.* . . . One-half of these genera scarcely, if at all, survive the Pottsville. Three or four only outlive the Allegheny. The Westphalian witnessed the maximum development in *Sphenopteris, Neuropteris,* and *Alethopteris,* and of the great Lycopod group. It is preeminently the stage of the Cycadofilices."[180]

Missourian or Upper Pennsylvanic. In the northern Appalachian area the Coal Measures or Missourian series embraces the Allegheny, Conemaugh, and Monongahela stages. As in the Pottsvillian below, these formations rarely have normal marine faunas, and when they are present the variety and abundance never equal that of the western area of the Mississippian sea. The lower half of the Conemaugh has at least three distinctly marine horizons—Brush creek, Pine creek, and the Ames or "crinoidal limestone." In the first or lowest horizon, Raymond[181] has found *Marginifera wabashensis, Astartella vera, Patellostium montfortianum, Euphemus carbonarius, Bellerophon percarinatus, Trepospira illinoisensis, Worthenia tabulata, Sphærodoma primagenia, Bulimorpha nitidula,* and *Euomphalus catilloides.* Just below the Ames limestone, in "red structureless clay," "at least 725 feet below the Permian (Dunkard series)," he has also found bones of Amphibia and Reptilia, recently described by Case (ibid., 1908). These remains pertain to *Eryops,* the diadectid reptile *Desmatodon hollandi,* and the pelycosaurid reptile *Naosaurus* (?) *raymondi.* This discovery is of very great interest, as showing that the Permic reptilian fauna was in existence as early as middle Upper Pennsylvanic time. The forms represented appear to be more primitive than those of the Wichita, thought to lie at the base of the Permic. In the northern Appalachian area, the Ames limestone marks the last marine invasion during Pennsylvanic time. The higher limestones are without marine fossils, and are regarded as of fresh-water origin, owing to the presence in them of from 2 to 5 coal seams. The fossils are said to be common at times,[182] but of few species, usually Ostracoda, *Spirorbis anthracosia,* and *Anthracopupa ohioensis* ?.

The Upper Pennsylvanic deposits of the northern Appalachian area are correlated by D. White[183] as follows:

> "I would provisionally place the greater part, if not all, of the Conemaugh together with the Monongahela in the Stephanian. . . . The Stephanian or

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[180] D. White: Journal of Geology, vol. 17, 1909, pp. 327-328.

[181] Raymond: Annual Report of the Carnegie Museum, 1909, p. 169.

[182] Hyde: American Journal of Science, vol. 25, 1908.

[183] White: Journal of Geology, vol. 17, 1909, p. 329.

Ouralian (including the Gschellian) of Europe dates from the Hercynian uplift. Prior to this movement the sea had reached its maximum extension in the coalfields of the northern hemisphere. . . . The final exclusion of the sea from the Appalachian trough appears to have occurred soon after the deposition of the Ames limestone, near the middle of the Conemaugh. . . . It is probable that the Monongahela was never deposited in the southern Appalachian region, from portions of which the Conemaugh may also have been absent.

"In eastern America, where the relations of land and water were but gradually altered and the sedimentation was continuous, the passage to the Stephanian flora has no line of sharp paleobotanical demarkation." For the same reason "the Stephanian types persist far up into the Dunkard formation.

"The Stephanian is marked by the great development of *Pecopteris*, *Callipteridium*, and *Odontopteris* of the true type. It witnessed the nearly complete disappearance of *Alethopteris*, *Sigillaria*, and *Lepidodendron*. . . . Before its close appear the first representatives of *Callipteris*, *Walchia*, *Tæniopteris* of the simple type, *Pterophyllum*, *Zamites*, and *Plagiozamites*, all characteristic of the Permian or later periods."

In the upper Mississippi valley, and especially in Kansas, Nebraska, Iowa, Missouri, and Illinois, the deposits of the Missourian are usually of normal marine origin, and here the fossils of this time occur in abundance. The term Missourian has been selected for this series in preference to Coal Measures. As finally defined by Keyes, Missourian embraces all between the Cottonwood at the top of the Kansas section and the Winterset of Iowa or the Bethany of Missouri, which represents the base. The writer, however, makes use of the term to include all of the Kansas section from the base of the Cherokee to the top of the Neosho (see table, page 558), preferring thus to extend the meaning of Missourian rather than to coin another new term.

Thus far no well defined, or, rather, easily discerned, zones have been pointed out. Girty[184] has determined a mass of material, collected at nearly 500 stations in Kansas, and representing 164 species. These are arranged in 46 stratigraphic zones as determined by Adams. The lowest horizon is the Cherokee at the base of the Missourian, and probably extending into the late Pottsvillian. The seven highest zones are generally referred to the Permic or "Permo-Carboniferous." Girty states: "The table shows the evolution of the latest from the earliest faunas in the section to have been a progression from a brachiopod to a pelecypod facies. . . . It is without marked interruption at any point, so that subdivisions appropriate for recognition are not clearly apparent." *Chonetes mesolobus* is restricted to the six basal zones. The following are the more characteristic fossils of the Missourian, restricting the term in this case to the zones above the Cherokee and below the Wreford, or to zones 2 to 39, inclusive, of the table: *Triticites secalicus, Lophophyllum proliferum, Campophyllum torquium, Chætetes milleporaceus, Eupachycrinus magister, Erisocrinus typus, Ceriocrinus hemisphericus, Phialocrinus magnificus, Rhipidomella pecosi, Enteletes hemiplicata, Orthotetes crassa, Meekella striaticostata* (also in Permic), *Chonetes flemingi, C. verneuilianus, Productus cora, P. nebrascensis, P. pertenuis, Marginifera wabashensis* (also above), *Aulacorhynchus millipunctatus, Spirifer cameratus, Spiriferina kentuckyensis, Composita subtilita* (also above), *Dielasma bovidens, Hustedia mormoni, Pugnax utah, Aviculopecten occidentalis* (also above), *A. carboniferus, Myalina subquadrata, M. perattenuata* (also above), *M. swallovi, M. kansasensis, Lima retifera, Allorisma terminale* (also above), *Limoptera, Pteria, Pleurophorus, Pseudomonotis hawni* (most common above; the genus first appears in zone 16), *Soleniscus ponderosus, Trachydomia wheeleri, Trepospira sphærulata, Worthenia tabulata, Phanerotrema grayvillensis, Euphemus carbonarius,* and *Bellerophon crassus.*

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[184] Girty: Bull. no. 211, U. S. Geological Survey, 1903.

Elsewhere in the Coal Measures these goniatites are found or the ammonites *Agathiceras ciscoense* (Cisco only), *Dimorphoceras texanum* (Cisco only), *Gastrioceras globulosum* (Cisco), *G. illinoisense* (Illinois), *G. kansasense* (Missouri and Kansas), *G. montgomeryense* (Illinois), *G. planorbiforme* (Missouri), *G. subcavum* (Illinois and Texas), *Gonioloboceras welleri* (Illinois and Texas), *Popanoceras ganti* (Cisco; the genus extends upward), *P. parkeri* (Strawn of Texas), *Schistoceras* (four species restricted to the Coal Measures in Ohio, Illinois, Missouri, and Texas), *Schuchertites grahami* (Cisco only), and *Shumardites simondsi* (Cisco only).

The plants of the Missourian in Kansas have been studied by D. White,[185] and his conclusions are as follows: "The flora of the Cherokee at the base of the 'Coal Measures' falls within the Allegheny formation of the Appalachian basin." Elsewhere it has "close relationship with the Cherokee flora of Henry county, Missouri, [and] the Mazon Creek stage of the Illinois Coal Measures." About the middle of the Pottawatomie (see table, page 558) is another floral horizon that does not "seem to be of an earlier date than the Freeport, the uppermost division of the Allegheny formation" (ibid., 112). At the base of the Douglass the plants seem "to point toward a level possibly as high as the Pittsburg coal" at the base of the Monongahela (ibid., 114). Those near the top of the Shawnee are also Monongahela. Near the top of the Wabaunsee the flora is

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[185] White: Bull. no. 211, U. S. Geological Survey, 1903, p. 111.

"clearly indicative of a stage at least very high in the Upper Carboniferous (Pennsylvanic). Nearly all the species have been reported from either the Permian of Europe or the Dunkard formation of the United States. . . . Yet the small flora from Onaga [Wabaunsee stage] contains none of the special types or characteristic Permian forms which are present in the Dunkard, and on account of which the greater part of the Dunkard is regarded as Permian" (ibid., 115). Judging from the evidence furnished by the invertebrates, this formation is best left in the Pennsylvanic system.

In the Rocky Mountain region the late Pottsvillian faunas everywhere appear to have been followed by an erosion or land interval. How long this emergence persisted can not as yet be estimated, but the Mississippian sea, with its well known Missourian fauna, apparently reentered the Rocky Mountain area long before the close of the Pennsylvanic, and then, under practically the same physical conditions as those of the Mississippi valley, continued well into the "Permo-Carboniferous" or Oklahomian epoch. The Californian sea extended east into the Cordilleran region to the west of a land barrier, and late in the Pennsylvanic almost united with the Mississippian sea. Both marine areas then persisted independently into Oklahomian time, but the Pacific waters in the Sonoran sea continued long after the Mississippian sea had vanished in red beds and gypsum deposits. The spread of these waters will now be taken up in greater detail.

According to Cross,[186] the Hermosa formation of limestones, shales, and sandstones occurs in southwestern Colorado, with a maximum thickness of 2,000 feet. The Molasse is at the bottom of the Hermosa. According to Girty, the fauna "is probably older than the 'Upper Coal Measures' faunas of the Kansas and Nebraska sections." Nearly all the forms are those of the Mississippi valley. Some of these are: *Triticites secalicus, Chætetes milleporaceus, Prismopora serrata, Meekella striaticostata, Chonetes mesolobus, Productus cora, P. punctatus, P. nebrascensis, Marginifera wabashensis, Spirifer rockymontanus, S. cameratus, Squamularia perplexa, Spiriferina campestris, Composita subtilita, Myalina subquadrata, Bellerophon crassus, Patellostium montfortianum, Euphemus nodocarinatus,* and *Phillipsia major.*

At Moab, Utah, and in Sinbad valley, on the Colorado-Utah line, Girty[187] has also determined *Syringopora multattenuata, Lophophyllum profundum, Campophyllum torquium, Axophyllum rude, Enteletes hemi-*

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[186] Cross: Folios 120, 130, 131, and 153, U. S. Geological Survey.

[187] Girty in Cross: Journal of Geology, 1907, pp. 668-676.

plicatus, Chonetes granulifer, Hustedia mormoni, Dielasma bovidens, Chænomya leavenworthensis, etcetera.

To the writer, the Hermosa appears to be best correlated with the Upper Missourian. Girty, however, correlates the Weber and the Lower Maroon of northwestern Colorado with the Hermosa. The Weber conglomerate and sandstone represent, according to Hague,[188] "one of the most persistent and well defined horizons over wide areas of the Cordillera, stretching westward all the way from the Front Range in Colorado to the Eureka mountains." In the Eureka district the "thickness is estimated at about 2,000 feet" (8,000 in the Oquirrh mountains). No fossils occur here. In Nevada, above the Weber, follow the "Upper Coal Measures" limestones, attaining a depth of nearly 2,000 feet. The fauna is essentially the same as that of the Missourian of the Mississippi valley. In Nevada the series is terminated by limestones nearly 2,000 feet thick, bearing the same fauna, and with a few lignite seams up to 18 inches in thickness.

Upon the Hermosa, in southwestern Colorado, is laid down conformably the Rico formation of sandstones and conglomerates, with intercalated shales and thin fossiliferous limestones. The thickness is about 300 feet. Girty[189] reports some of the fossils to be: *Productus cora, Composita subtilita, Limipecten occidentalis, Myalina wyomingensis, Pseudomonotis hawni, P. equistriata, P. kansasensis, Pleurophorus subcostatus, Naticopsis monilifera,* etcetera. These species indicate the Permo-Carboniferous beds of the Kansas section and they show the fauna to be that of the Mississippian sea. Cross and Howe[190] state:

> "The Hermosa formation appears to occupy the same stratigraphic position as the Aubrey of Utah and Arizona. Further investigations are necessary, however, to explain certain faunal differences or dissimilarities noted by paleontologists between the formations."

The Aubrey fauna is clearly of the western or Pacific realm.

Apparently the Rico equivalent also occurs in the Wahsatch mountains, here consisting of argillaceous and calcareous shales, with muddy marls 650 feet in thickness. The fauna includes *Pseudomonotis hawni.*[191]

Above the Rico and Hermosa, in southwestern Colorado, are the unfossiliferous "Red Beds" forming the Cutler deposits. According to Cross,[192] their thickness is not less than 2,000 feet. Above is an erosion interval followed by the Dolores formation of Upper Triassic age. The Cutler consists of cross-bedded conglomerates, grits, gypsum beds, and red shales, which "are mainly continental deposits." "As distance from the mountain source of these clastic materials increases, the beds are naturally finer grained and grade into shales and marls, and correlation of widely separated sections becomes difficult."[193] This horizon is believed to be the continuation of the Oklahomian series of the Kansas section.

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[188] Hague: Monograph 20, U. S. Geological Survey, 1892, pp. 91-92.

[189] Girty in Cross: Folio 130, U. S. Geological Survey, 1905.

[190] Cross and Howe: Bull. Geological Society of America, vol. 16, 1905.

[191] King: U. S. Geological Survey of the 40th Parallel, vol. 1, 1878, pp. 164, 173, 245.

[192] Cross: Folios 120, 130, 141, and 153, U. S. Geological Survey, 1907.

The Chugwater red beds of Wyoming, averaging 1,200 feet in depth, appear to hold the horizon of the Cutler. The fossils are few and there are no brachiopods. The forms represented are: *Schizodus wheeleri, Aviculopecten curticardinalis, Pleurophorus, Bakewellia* ?, and *Natica lelia.*[194]

In southwestern Wyoming occurs the Thayer formation, with a thickness of 2,400 feet. It probably is the equivalent of the Chugwater and Cutler. The fauna of these beds is composed of pelecypods, some of which are: *Aviculopecten weberensis, A. curticardinalis, A. parvulus, Myalina permiana, Myacites inconspicuous* ?, *Bakewellia* ?, *Schizodus ovatus, Sedgwickia concava.* "They indicate an extension into Wyoming of the Permo-Carboniferous of the Wasatch range."[195]

Permic of the northern Appalachian sea.—In this area marine faunas ceased in the upper part of the Conemaugh, and all subsequent deposits are of continental origin. If these are brackish-water deposits, there is as yet no evidence of the fact known to the writer. Above the Monongahela rests the Dunkard series of western Pennsylvania, eastern Ohio, and West Virginia. The plants of these beds are Lower Permic, on the authority of D. White, equivalent to the Atunian and Cuseler of Europe. The reference in 1880 of the Dunkard to the Permic, by Fontaine and I. C. White, "has been doubted by most American geologists. Recently, however, additional plant evidence has been obtained to show that the beds above the Washington coal, 175 feet above the Waynesburg coal [the base of the Dunkard], are clearly Lower Rothliegende (cf. Cuseler); and it is not impossible that the Rothliegende boundary may, on the acquisition of further paleontological material, be shown to lie unquestionably below the Waynesburg coal."[196]

From a parting of the Waynesburg coal near Cassville, West Virginia, at the very base of the Dunkard, Lacoe obtained many insects. Others have been found at Fairplay, Colorado. These have been studied by Handlirsch,[197] who has determined 93 forms. All belong to the Blattoidea and best agree with those of the Cuseler. He states that the Palæodictyoptera so characteristic of the Missourian are absent here. The evidence furnished by the insects is therefore in harmony with that of the plants.

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[193] Cross: Journal of Geology, 1907, pp. 662-668.

[194] Darton: Bull. Geological Society of America, vol. 19, 1908, p. 438.

[195] Girty in Veatch: Professional Paper no. 56, U. S. Geological Survey, 1907, p. 52.

[196] D. White: Proceedings of the U. S. National Museum, vol. 29, 1906, p. 665.

[197] Handlirsch: Fossilen Insekten, 1906-1908, p. 1149.

Permic of the Mississippian sea.—In this province the Missourian marine deposits pass without break into the "Permo-Carboniferous," and stratigraphers have differed as to where in this section the line should be drawn between the Pennsylvanic and the Permic. There is no natural limit here, and the line of separation must always be an arbitrary one. The other debated question is, Shall these higher deposits be referred to the Pennsylvanic or to the Permic system? The answer will depend on whether the Permic shall be restricted to the type area—the Perm region of the Ural mountains of Russia—or whether the view shall be adopted that the Russian formation known as the Artinsk is best referred to the Permic, using this term in the wider sense. The latter view is the one more generally accepted, and also the one adopted here. Following the work of Prosser, the writer will therefore draw the Permic line at the base of the Wreford limestone of Kansas. Not many typical Missourian species pass above this line, and most of these begin in the upper part of the Pennsylvanic. Of the 164 Kansas species listed by Girty,[198] 46 pass into the basal Permic beds known as the Chase and Sumner, and 12 are restricted to them. Of the former, 24 range throughout the Missourian, and some of these even from the Pottsvillian; 14 others begin near the middle of the Missourian, and 8 take their rise a little below the Wreford. These figures show that there is here a complete transition, but, as will be seen, the faunal changes are largely brought about by the dropping out of the brachiopods and the appearance of new forms, chiefly pelecypods, but in the south of ammonites. For this transition series the writer adopts Keyes's Oklahomian, as his emended definition embraces all the so-called Permo-Carboniferous. The series, therefore, represents the lower portion of the Permic in the wider sense, and it is all probably older than the true Permic of the Perm district of European Russia.

The more characteristic fossils of these transition beds are: *Pseudomonotis hawni* (this form also occurs below, and the genus goes about half way down in the Missourian), *Myalina aviculoides* (below), *M. permiana, Bakewellia* (?) *parva,* (below), *Pleurophorus calhouni, P. subcuneatus, Sedgwickia altirostrata, Chænomya leavenworthensis, C. minnehaha,* and *Phacoceras dumblei* (Fort Riley limestone). Other forms not so characteristic are: *Orthotetes robusta, Meekella striaticostata, Productus nebrascensis, Marginifera wabashensis,* and *Composita subtilita.*

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[198] Girty: Bull. no. 211, U. S. Geological Survey, 1903.

In the Kansas section, near the top of the Sumner, occurs a flora that Sellards regards as of Lower Permic age. This conclusion is borne out by White's[199] statement that

> "if the composition of the entire flora proves to be of so young a character as the material described or placed in my hands by Mr Sellards, his conclusion that the beds are of so late date as the Lower Permian will appear to be fully justified. . . . Probably of a date fully as late as the earlier of the floras generally referred to the Permian in western Europe."

The Sumner formation also yields an abundant insect fauna very different from that of the Pennsylvanic. But few of these are as yet described by Sellards.[200] "Over two thousand specimens are now at hand [and give] the most complete record of Permian insect life thus far obtained." Ephemerids are unknown beneath the Permic, and Sellards here described 12 new species.

In Texas occur far more characteristic Oklahomian fossils associated with many Pennsylvanic survivors. In the Albany series are the ammonites *Phacoceras dumblei* (also in the Fort Riley limestone of Kansas), *Medlicottia copei, Popanoceras walcotti, Paralegoceras taylorense, Waagenoceras cumminsi,* and *Coloceras globulare.* Of nautiloids occur *Domatoceras simplex, D. militarium, Tainoceras occidentalis* (also below), *Temnocheilus winslowi* (below), and *T. conchiferus.* In the Double Mountain series (which may be but another petrologic phase of the Albany and Wichita), *Waagenoceras hilli* is found. These forms are thought to hold the time of the European Artinsk, referred by stratigraphers to the Permo-Carboniferous or the Lower Permic.

Concerning the divisions of the Wichita, Clear Fork, and Double Mountain, Adams[201] states:

> "It may be said that there is little reason to believe that they should be any longer retained, since they have no stratigraphic significance. It appears that what have been called the Clear fork and Wichita divisions by Mr Cummins are the equivalents, in part at least, of the Albany."

The Wichita-Brazos region has been restudied by Gordon,[202] and his conclusions are as follows: The Wichita and Clear Fork, usually regarded as of Permic age,

> "when traced along their strike toward the southwest, are found to grade into those included under the terms Cisco and Albany. . . . An abundant marine fauna characterizes the beds toward the south. In the Red Bed region marine

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[199] White: Bull. no. 211, U. S. Geological Survey, 1903, p. 117.

[200] Sellards: American Journal of Science, September, 1906, and May, 1907.

[201] Adams: Bull. of the Geological Society of America, vol. 14, 1903.

[202] Gordon: Science, May 7, 1909, p. 752.

forms are few, appearing only in the few beds of limestone that persist. Along with them in this region appear vertebrate remains upon which the references to the Permian have been based. It is the conclusion of the author that the Red Beds of this region are the near-shore representatives of the Albany and the decision as to their age will rest upon that of the latter."

In this connection it should be stated that Cummins[203] has recently given "the localities and horizons of Permian vertebrate fossils in Texas." He shows that the two divisions Wichita (includes the Albany) and Clear Fork have distinct vertebrate associations (the Double Mountain division is almost devoid of these remains). The Wichita is marked by the stegocephalian genus *Cricotus,* by the reptilian Cotylosauria genera *Chilonyx* and *Bolosaurus,* and the reptilian Pelycosauria genera *Clepsydrops, Ctenosaurus, Theropleura, Metamosaurus, Paleosaurus,* and *Embolophorus.*

Restricted to the Clear Fork there are of Stegocephalia *Diplocaulus, Dissorhopus, Acheloma,* and *Anisodexis;* of Cotylosauria *Bolbodon, Isodectes, Hypopnous,* and *Labidosaurus;* all the Chelydosauria; and of Pelycosauria *Edaphosaurus.*

Common to the Wichita and Clear Fork there are of Stegocephalia *Trimerorhacis, Zatrachys,* and *Eryops;* of Pelycosauria *Diadectes, Empedias, Pariotichus,* and *Pantylus;* of Pelycosauria *Dimetrodon* and *Naosaurus.* With this evidence at hand, it must be agreed, at least for the present, "that the divisions of Wichita and Clear Fork which were proposed at first on purely stratigraphic grounds are fully warranted and upheld by the fossils found in them" (Cummins).

In the Whitehorse member of the Woodward division, Beede[204] describes among others from Oklahoma *Dielasma schucherti* (certainly a Permic type of brachiopod) and a number of pelecypods. From the Quartermaster division come the same brachiopod, many new pelecypods, and univalves.

In the Red Beds of the Enid of Oklahoma there has been found the phyllopod *Estheria minuta,* the amphibians *Eryops megacephalus, Diplocaulus, Trimerorhachis, Cricotus, Cricotillus* (restricted here), and *Crossotelus;* and the reptiles *Naosaurus, Pariotichus,* and *Pleuristion.* These belong to the same general land fauna as that found in the Wichita of Texas. The latter area contains a far greater number of amphibians and reptiles, which have been described by Cope. Recently Case[205] has restudied the Pelycosauria.

The plants collected by Cummins in the Wichita are, according to Fontaine and I. C. White,[206] identical with those of the Dunkard Creek series of West Virginia. This series begins with the Waynesburg coal, and White has always regarded it as recording the time of the Permic.

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[203] Cummins: Journal of Geology, vol. 16, 1908.

[204] Beede: Kansas University of Science, Bull. no. 4, 1907.

[205] Case: Publication no. 55, Carnegie Institution of Washington, 1907.

[206] White: Bull. Geological Society of America, vol. 3, 1892, p. 217.

Case[207] has recently reviewed the vertebrate evidence on which Americans have placed such dependence as proving the Permic age of the Wichita red beds of Texas. Since Raymond found reptiles in the middle Conemaugh, which is even below the Monongahela, the uppermost series of the Pennsylvanic, reliance can no longer be placed on the mere presence of reptiles as positive proof for Permic age. This discovery led to Case's review, and he concludes as follows: "The evidence from vertebrates is not sufficient to demonstrate the Permian age of the beds in Illinois and Texas; they may reach down into the Carboniferous."

It is now fairly well established that the Wichita and its fauna and flora are not of true Permic time, but belong to the older Permic, the so-called Permo-Carboniferous or Oklahomian, or the European Artinsk. The Wichita flora correlates with the Dunkard, and the latter with the European continental deposits, the Atunian and Cuseler, or the Rothliegende. It is even possible that the Wichita is slightly older than the latter, but in any event the ammonites correlate best with the Artinsk.

Throughout the Mississippian sea the Oklahomian deposits are those of a vanishing sea with abnormal marine conditions. Vast areas consist of nothing but red beds, with here and there thin dolomite layers, and in many places gypsum occurs in quantity, especially in Oklahoma, the "Gypsum State." In Kansas the earliest Oklahomian deposits are still those of normal marine waters, and this condition probably continues longest in the Albany of Texas.

Californian sea.—In California the equivalent of the Pennsylvanic has at its base the Bragdon "shales, sandstones, and tuffs, with siliceous conglomerates (of Devonian pebbles) increasing in number and size from the top toward the bottom."[208] The thickness is estimated at 2,900 feet, and may attain to 6,000 feet. The fossils of this formation are very few, but these link it directly with the overlying Baird. Among other forms were found a *Glyphioceras* similar to *sphæricus* and *Lithostrotion sublæve.* Diller refers this formation to the Mississippian. It may be that this zone is older than the Pottsvillian, in which case it is of late Tennesseic time. All depends on the age of the following Baird, which Diller[209] also refers to the Mississippian, but which the writer regards as very early Pennsylvanic—that is, Lower Pottsvillian.

The Baird "reddish shales and sandstones with much volcanic material" are estimated by Diller to have 1,000 feet of thickness. Near the United States Fishery Station, on the McCloud river, is found an abundance of fossils, a good collection of which is now in the U. S. National Museum. They occur in the upper 150 feet of the Baird, and were provisionally identified about fifteen years ago by the writer. The fauna may be known as the *Productus giganteus.* Some of the more characteristic forms are: *Productus giganteus* (not typical with the European species of Martin), *P. punctatus, P. semireticulatus, Cleiothyridina roysii* ?, large *Camarophoria, Rhipidomella corallina* (Waagen), *Bellerophon* cf. *stevensanus, Pleurotomaria* cf. *newportensis,* and *carbonaria, P.* cf. *subsinuata, Bulimorpha nitidula, Aviculopecten interlineatus, Streblopteria, Lima retifera, Edmondia* cf. *aspinwallensis, Pleurophorus* (3 species), and *Allorisma.*

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[207] Case: Journal of Geology, 1908, p. 580.

[208] Diller: American Journal of Science, vol. 19, 1905, p. 383.

[209] Diller: Folio 138, U. S. Geological Survey, 1906.

From the foregoing list it may be seen that the fauna has a decided Pennsylvanic aspect and that some of the species are also found in the Mississippi valley. Associated with these are forms clearly of Asiatic origin, which become more common in the higher beds. As there is practically nothing in this fauna resembling that of the Tennesseic, it is here regarded as of early Pennsylvanic time, and is probably the equivalent of the Lower Pottsville of the Appalachian and Mississippian seas. Smith[210] refers the horizon to the Lower Carboniferous, and identifies in it (in all probability erroneously) Mississippic, Tennesseic, and Pennsylvanic forms. The Russian geologists refer their *Productus giganteus* zone to the Lower Carboniferous, which they correlate with the Belgian Viséian.

Daly has collected and Ami has identified *Productus giganteus* in the Flathead river region of southwestern British Columbia. In southeastern Alaska, on Chichagof island, at Freshwater bay, Kindle has found the same species. From these occurrences it is seen that this fauna is widespread along the Pacific coast, but thus far it is not reported from the Arctic regions, although *Spirifer mosquensis* of the next higher zone is said to occur there. According to G. M. Dawson,[211] this and the later Pennsylvanic sediments are widely distributed in British Columbia, and are "mingled with contemporaneous volcanic materials, . . . tranquil epochs being marked by the intercalation of occasional limestone beds."

Above the Baird shales follows the McCloud limestone, said by Diller to vary between 200 and 2,000 feet in thickness. At the base is found the *Omphalotrochus whitneyi* fauna in part described by Meek in the California Report. Besides this large gastropod, there is an abundance of the foraminifer *Schwagerina* and the corals *Clisiophyllum gabbi, Lonsdalia sublævis, L. californiense, Syringopora multattenuata* ?, *Hustedia compressa,* etcetera. Girty[212] correlates this formation with "the lower portion of the Hueco." The latter "will perhaps prove to be the same as the Aubrey formation of northern Arizona," both of which are regarded as of late Pennsylvanic age. This horizon also appears in Alaska and the Arctic regions, being here marked by *Spiriferella arctica.* When these strange faunas were first seen by the writer,[213] particularly because of the variety of the Producti, he regarded their age as Permic. It is now known that they correlate best with the Omphalotrochus and higher Pennsylvanic faunas of California and Russia. The writer was first impressed with this resemblance while on a visit to the Geological Survey collection at Saint Petersburg, in 1903, and he still regards the Alaskan faunas as best compared with the Omphalotrochus and *Productus cora* zones of Russia.

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[210] Smith: Journal of Geology, 1894, pp. 594-599.

[211] Dawson: Bull. Geological Society of America, vol. 12, 1901, p. 85.

The McCloud limestone is succeeded by the McCloud shale, or Nosoni formation, "composed very largely of andesite or basalt tuffs and tuffaceous conglomerates and a few flows of lava, but locally interstratified with these volcanic products are shales and sandstones, in part calcareous, and often rich in fossils." The thickness varies between 500 and 1,200 feet. On Little Grizzly creek, Plumas county, occur *Fusulina elongata, Chonetes* (a large new form), *Marginifera longispina, Rhipodomella pecosi, Pugnax utah* ?, *Uncinulus* cf. *theobaldi, Meekella* cf. *striaticostata, Spirifer* much like *camerata* and *musakheylensis.* Girty states that the "McCloud shale may provisionally be correlated with the upper Hueconian." It also seems to correlate with the Schwagerina zone of the Russian geologists. This zone is just below the Permo-Carboniferous or Artinskian.

Hueconian (*Pennsylvanic*) *of the Trans-Pecos region of Texas.*—In this part of Texas there is no equivalent of the Pottsvillian, the Hueconian apparently representing the Upper Missourian of the Cordilleran region. The Hueco formation consists of a massive limestone with zones of shale and sandstones, ranging in thickness from 3,000 to 5,000 feet. The fauna found at the base is somewhat similar to that of the late Pottsvillian, but the higher assemblages are quite different from those of the Pennsylvanic of the Mississippi valley and are mostly undescribed. "Through the West, however, these faunas will probably prove to have extended widely." The Hueco "will perhaps prove to be the same as the Aubrey formation of northern Arizona" (Girty, 1905, 14).

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[212] Girty: Proceedings of the Washington Academy of Sciences, vol. 7, 1905, p. 16.

[213] Schuchert in Mendenhall: Professional Paper no. 41, U. S. Geological Survey, 1905, pp. 42-45; also Kindle, Journal of Geology, 1907.

Near the base of the Hueco, Girty records *Triticites, Productus cora, Marginifera* cf. *wabashensis, Squamularia perplexa, Spirifer rockymontanus.* It will be seen that these forms are suggestive of those of the higher Pottsvillian. In higher beds at different horizons, Girty[214] collected among other forms *Fusulina elongata, Schwagerina* ?, *Lithostrotion, Chætetes milliporaceus, Orthothetina, Enteletes, Camarophoria,* related to European forms; *Pugnax, Productus,* related to Ural and Aubrey forms; *Spirifer* cf. *marcoui, Hustedia, Composita mexicana, Omphalotrochus obtusispira,* etcetera.

The Aubrey extends to within 25 miles of Moab, Utah, yet its fauna is very different from that of the Hermosa of the Mississippian sea. The writer believes that the Aubrey faunas are younger than those of the Hermosa, but still Pennsylvanic, and of a distinct faunal province—that is, of the western or Cordilleran basin. The Aubrey limestone on Kanab creek attains a depth of 820 feet, while the underlying Aubrey sandstones, with gypsum, along the Grand Canyon reach about 1,000 feet.[215]

In the Grand Canyon region the Aubrey is followed by the Shinumo sandstone, 250 feet in thickness. It appears to be a dune sandstone formation. Above this is the Sublime limestone and calcareous sandstone about 600 feet in thickness, near the middle of which, in a zone 200 feet thick, occurs the fauna described by Newberry. This is the *Productus ivesi* fauna, and includes *Archæocidaris longispina, Meekella occidentalis, M. pyramidalis, Productus ivesi* (the guide fossil), *P. nodosus, P. occidentalis, Aviculopecten coloradoensis,* and *Allorisma capax.* There are many other species, not one of which is familiar when compared with the eastern Missourian forms. In Utah are found *Chonetes utahensis, Productus semistriatus, P. multistriatus, Spirifer scobina, S. cameratus occidentalis,* and *Spiriferina pulchra.* The Embar formation of central Wyoming also displays the *S. pulchra* fauna. The Embar limestone, Girty[216] says, "has a very different fauna from the Kansas Permian, but it may be equivalent to it, or even later. The fauna is not related to the Guadalupian. It occurs in Utah just below the Permo-Carboniferous, and is known also in Idaho and Nevada."

In a very recent paper Girty[217] states:

> "The Mississippian faunas, together with the earlier Pennsylvanian ones, appear to be absent [in the Trans-Pecos region]. The Hueconian fauna is widely distributed over the West, ranging indeed into Alaska, while it is even

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[214] Girty in Richardson: Bull. no. 9, University of Texas Mining Survey, 1904.

[215] Spurr: Bull. no. 208, U. S. Geological Survey, 1903.

[216] Girty in Darton: Bull. Geological Society of America, vol. 19, 1908, p. 418.

[217] Girty: Journal of Geology, 1909, p. 311.

recognizable in Asia and eastern Europe. Most of the occurrences of Carboniferous in the West can be referred to this series, although some of them present more or less distinctive facies."

Guadalupian (Permic) of the Trans-Pecos region of Texas.—The Hueconian of this area is followed by the Guadalupian, but it is not known whether the succession is a continuous one or is broken. At the base are black non-magnesian, bituminous limestones, of which about 200 feet are visible. These are succeeded by the Delaware Mountain formation proper, consisting chiefly of sandstones in the north and of more calcareous material in the south, and having a thickness of from 1,200 to 1,500 feet. At the top are dark limestones not less than 100 feet thick, followed by the Capitan white massive limestone about 1,800 feet in depth. Richardson[218] refers the three lower members to the Delaware Mountain formation, while the fourth is the Capitan limestone.

These formations have yielded a fauna comprising 326 forms (220 are specifically named), described by Girty[219] in great detail. They are chiefly Protozoa (9 species), Sponges (24), Bryozoa (44), Brachiopoda (128; *Productus* 25), Pelecypoda (45), and Gastropoda (42). The fauna, while large, is a very strange one, being composed almost entirely of local forms, most of which are small in size. The life of the Guadalupian "is quite unlike the faunas of eastern North America, and almost equally unlike most of those of the West." "The nearest are probably those of the Salt Range and Himalaya, in India, and of the Fusulina limestone of Palermo, in Sicily." It "is younger than the Kansas 'Permian,' and . . . belongs to a different epoch."

The Delaware and Capitan have a very similar fauna, and are bound together by the following characteristic forms: *Fusulina elongata* (attains a length of more than one inch), a Mesozoic type of bryozoan near *Domopora,* the brachiopods *Streptorhynchus, Orthotetes, Leptodus americanus,* many species of sinused, coarsely spinose Producti, *Aulosteges, Richthofenia permiana, Nothothyris, Heterelasma,* many *Spiriferina,* the pelecypods *Pteria,* and a Mesozoic genus near *Camptonectes.*

In the basal black limestone of the Delaware formation the fauna in some respects retains a Hueconian facies, but that it is of Permic time is shown by the presence of *Richthofenia permiana, Aulosteges* (2 species), *Paraceltites elegans, Peritrochia erebus,* and *Agathoceras texanum.* The survivors are *Enteletes, Meekella, Pugnax osagensis* (a Missourian form of the Mississippi valley), *Clinopistha* ?, *Leda, Yoldia,* and *Naticopsis.*

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[218] Richardson: Bull. no. 9, University of Texas Mining Survey, 1904, p. 38.
[219] Girty: Professional Paper no. 58, U. S. Geological Survey, 1908, pp. 28, 39.

The higher Delaware formation introduces among other forms *Fusilinella, Leptodus americanus* (goes above), *Richthofenia permiana* (goes above), *Enteletes dumblei, E. angulatus, Strophalosia hystricula, Aulosteges magnicostatus, Meekella skenoides, M. difficilis, Orthotetes nasuta* (large, of *robusta* type),*Camarophoria venusta, Hustedia bipartita, Bakewellia ?, Pteria* (3), *Myoconcha, Pleurophorus, Warthia americana, Waagenoceras cumminsi guadalupense,* and the trilobite *Anisopyge perannulata* (goes above).

Besides those mentioned above, the Capitan has the following distinctive forms: *Geyerella americana, Leptodus guadalupensis, Strophalosia cornelliana* (also in Brazil), *Pugnax swallowiana, Dielasma prolongatum, Dielasmina guadalupensis, Heterelasma* (2), *Spirifer mexicanus, S. sulcifer, Spiriferina* (7), *Composita emarginata, Hustedia meekana* (also below), *Camptonectes ?* (3), and *Patella capitanensis.*

MESOZOIC ERA

Triassic Period

See plates 86 and 87

The widely emergent condition of the Permic persists into the Triassic, and in all eastern North America not a trace of marine deposits again appears until well into the Cretacic. Along the border region from South Carolina to Nova Scotia, east of the Appalachians, in isolated structural valleys, continental sediments accumulated, usually red in color, but at the south with coal beds ranging in thickness up to 26 feet. These strata are also known as the Newark series, and are sometimes regarded as extending into the Jurassic, but the plants all seem to be of Triassic time. In the northern areas there are many associated trap flows, both intrusive and extrusive.

Marine Triassic of the Pacific realm.—The emergent condition of eastern North America throughout the Triassic is recorded all the way to the Pacific by the absence of marine formations. The marine record is unusually complete in a restricted sea covering parts of California, Nevada, Oregon, and Idaho, in sediments with considerable calcareous material aggregating nearly 4,000 feet in depth. This series is rich in ammonites.[220] The faunas are Pacific and Asiatic, with decided connections with the great mediterranean Tethys.

The lowest Triassic or Meekoceras fauna of California and Idaho Smith[221] states to be a typical Pacific element, common also to the Himalayas, southern Siberia, and northern Tibet. He also reports that a little later the Tirolites fauna appears, having a decided Mediterranean aspect, but enduring for a short time, and that the Lower Triassic closes with the Columbites biota of few species, having boreal or northern Siberian characteristics.

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[220] J. P. Smith: Professional Paper no. 40, U. S. Geological Survey, 1905.

[221] Smith: Festschrift v. Koenen, 1907.

Table of Western Triassic Formations. After Smith, 1907

<table>
<tr><th></th><th></th><th>California</th><th colspan="2">Nevada</th><th colspan="2">Idaho</th><th>British Columbia</th></tr>
<tr><td rowspan="7">Upper Triassic</td><td></td><td>*Pseudomonotis subcircularis* slates</td><td colspan="2">Pseudomonotis slates</td><td colspan="2"></td><td>Pseudomonotis slates</td></tr>
<tr><td rowspan="5">Hosselkus limestone</td><td>Spiriferina beds</td><td colspan="2" rowspan="6">Star Peak li.
No characteristic fossils</td><td colspan="2" rowspan="8"></td><td></td></tr>
<tr><td>Juvavites beds</td><td rowspan="3">Dawsonites beds</td></tr>
<tr><td>*Tropites subbulatus* beds</td></tr>
<tr><td>*Halobia superba* beds</td></tr>
<tr><td>Slates with *Halobia* cf. *rugosa*</td><td rowspan="3">Daonella beds</td></tr>
<tr><td rowspan="4">Pit formation</td><td rowspan="2">Slates and tuffs without determinable fossils</td></tr>
<tr><td rowspan="5">Middle Triassic</td><td rowspan="2">Daonella li., Humboldt range</td><td>Gymnites beds</td></tr>
<tr><td rowspan="2">Clay and siliceous slates with *Anolcites* cf. *whitneyi* and *Ceratites* cf. *humboldtensis*</td><td>*Daonella dubia, Ceratites trinodosus* beds</td><td rowspan="6"></td></tr>
<tr><td colspan="2" rowspan="5"></td><td rowspan="5">Aspen</td><td rowspan="2">Columbites beds</td></tr>
<tr><td rowspan="4">Ceratite li., Inyo range</td><td rowspan="2">Black limestones with *Parapopanoceras, Xenodiscus, Arochordiceras,* and *Hungarites*</td></tr>
<tr><td>Tirolites beds</td></tr>
<tr><td rowspan="2">Lower Triassic</td><td>Calcareous slates without fossils</td><td rowspan="2">Meekoceras beds</td></tr>
<tr><td>Meekoceras beds of Inyo county, *Meekoceras gracilitatis, Ussuria, Pseudogeceras, Inyoites, Owenites, Nannites*</td></tr>
</table>

Triassic elevation still continued in the Rocky Mountain area, and all along the Pacific region there is constant proof of much volcanic activity, for according to Dawson[222] the Nicola and Vancouver series in British Columbia consists largely of volcanics and attains a thickness of 13,500 feet. Toward the close of the Lower Triassic the sea was withdrawn from

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[222] Dawson: Annual Report of the Geological Survey of Canada, vol. 7, 1896. Bull. of the Geological Society of America, vol. 12, 1901, pp. 57-92.

Idaho, but during the Middle Triassic the marine area of California and Nevada was extended into Oregon. The inundation thus started became general in the Upper Triassic all along the Pacific into Arctic Alaska, while in Mexico, for the first time since the Proterozoic, the Gulf of Mexico spread locally to Zacatecas. The Middle Triassic faunas of the west coast take on more of the Mediterranean type, and are directly correlated with the *Ceratites trinodosus* zone of Muschelkalk time. The Tethys connection is now so marked that, according to Smith,[223] "a paleontologist from Austria might be set down in the Humboldt desert, and he could hardly tell from the character of the fauna whether he was collecting in Bosnia or Nevada."

The widely distributed Upper Triassic begins in California with Halobia beds, followed by an abundant fauna referred to as the *Tropites subbulatus* zone of decided Mediterranean aspect, since many identical species occur in the two regions, which are more than 6,000 miles apart. With the same fauna appear various species of ichthyosauroids. The last of the Upper Triassic or Norian time returns to northern Asiatic or boreal conditions and widespread faunas, from Siberia to Japan and from Alaska to Peru. The Upper Triassic from Alaska to Vancouver has a limited fauna marked by *Pseudomonotis subcircularis.*

Newark series of continental deposits.—In the Connecticut valley there are from 10,000 to 13,000 feet of red granitic sandstones and shales, with horizons of black fossiliferous shales and traps. The upper series of sandstones, conglomerates, and shales, about 3,500 feet in thickness, have diverse types of dinosaur tracks, but very rarely is a skeleton found. The carnivorous forms are represented by *Anchisaurus colurus, A.* (?) *solus,* and *Thecodontosaurus polyzelus,* while the Predentata are present in *Ammosaurus major.* Skeletons of a crocodile-belodont reptile, *Stegomus longipes,* are also found. The middle series of sandstones, shales, and black shales, with three extrusive trap sheets, have a thickness ranging from 2,200 to 3,100 feet, of which the traps show a united depth of between 700 and 900 feet. In the black shales between the traps, representing temporary local bodies of fresh water, are found ganoid fishes of the genera *Redfieldius, Semionotus, Diplurus,* and *Ptycholepis.* Of plants, but 11 species are known (far more occur in the Richmond area) of *Otozamites latior, Pagiophyllum simile, P. brevifolium, Clathopteris platyphylla, Loperia carolinensis, Cycadinocarpus chapini, Equisetum, Baeria münsteriana,* and *Ctenophyllum braunianum angustum.* There are also tracks of large dinosaurs.

The lower series of coarse granitic sandstones, with frequent conglomerates and some shales, attain a thickness between 5,000 and 6,500 feet. Very rarely the track of a dinosaur occurs here also, and a single specimen of *Stegomus arcuatus* has been found. Also see pages 437 and 438.

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[223] Smith: Festschrift v. Koenen, 1907, p. 408.

In the southern or Richmond, Deep river, and Dan river area, Russell[224] states that there is much fine grained, black, highly bituminous slate, with decidedly local bituminous coals, and rarely a zone of black-band iron ore. The coal beds vary in thickness from a few feet to between 13 and 26 feet in occasional cases. In this area Emmons found the only so-called mammal jaws, *Dromotherium sylvestre* and *Microconodon tenuirostris.* Of reptiles are present *Belodon carolinensis, B. leaii,* and the amphibians *Pariostegus myops* and *Dictyocephalus elegans.* Of plants, about 72 species are recorded, among which is the broad-leafed giant fern *Macrotæniopteris magnifolia.* There are 8 species of conifers, 23 of cycads, 6 of *Equisetum,* and 35 ferns.

Continental deposits of the Rocky mountains.—The marine Triassic of California, Oregon, and Nevada early in this period extended into Idaho, and as continental deposits continued thence into eastern Wyoming. During the Lower Triassic the Pacific marine waters attained to southeastern Idaho, but apparently there is in this region also much material of a continental nature. Farther to the east all of the Triassic appears to be devoid of marine strata, and, according to Williston,[225] "in both Kansas and the Lander region of Wyoming, at least a thousand feet of continuous, conformable, uninterrupted, and homogeneous deposits of red sandstone, deposits utterly barren of all animal or plant remains," lie above the Permic and beneath the Upper Triassic, yielding Keuper types of reptiles. These red beds appear to be older than the far more widely distributed Upper Triassic, and all have accumulated under a semi-arid climate, and during a period of widespread crustal movements. The sea was gradually pushed westward, and in the Cordilleran region the area of continental deposits was greatly enlarged, with probable marine connections in British Columbia and southern California.

In many places in the Upper Triassic deposits occur scattered reptilian remains, making thin zones of bone conglomerates.[226] Here and there are also found fresh-water shells of Unio; likewise wood. In the Petrified Forest Park of Arizona occur prostrate tree trunks in abundance, some reaching a length of 120 feet, with a diameter of from 6 to 8 feet.

Triassic continental deposits are also known in Sonora and Oaxaca, Mexico. In the latter state Wieland informs the writer that the series is very thick and seemingly passes unbroken into marine deposits of Jurassic age. Plants are said to be abundant.

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[224] Russell: Bull. no. 85, U. S. Geological Survey, 1892.

[225] Williston: Journal of Geology, vol. 17, 1909, p. 396.

[226] Cross: Ibidem, 16, 1908.

Jurassic Period

See plates 88 to 90

Pacific region.—The unstable crustal condition along the Rocky Mountain axis during the Triassic was changed in early Jurassic times into epeirogenic elevation, thus removing the late Triassic submergence from all areas excepting that of the Cook Inlet and Selikoff region of Alaska, and the states of California, Oregon, and Nevada. With these movements there again appear in California marked faunal changes, for the boreal migrations of late Triassic times have ceased, and faunas with *Arietites* are now present, which Smith thinks may be South American invaders of Mediterranean derivation.

The Alaskan Lias submergence is continued into the Middle Jurassic of the Enochkin formation and has a thickness of 1,600 feet. According to Stanton and Martin,[227] the lower third of this series is marked by the bivalves *Inoceramus ambiguus, I. porrectus, I. eximius,* and *I. lucifer,* besides the ammonites *Stephanoceras loganium, S. carlottense, Sphæroceras oblatum,* and *S. cepoides.* Most of these shells also occur on the Queen Charlotte islands. The upper two-thirds of the Enochkin are marked by *Cadoceras doroschini, C. schmidti,* and *C. worsessenskii.*

Along the Pacific border the Middle Jurassic is continued into the Upper Jurassic. In the Cook Inlet country of Alaska the Enochkin persists without break into the Naknek, having a thickness of 5,000 feet or more (including some andesite). The guide fossil of this region is a boreal mollusk, either identical with or close to *Aucella pallasi.* With it are associated the boreal ammonites *Cardioceras alternans* and *C. cordatus.*

At or near the close of the Middle Jurassic, or, according to Stanton and Martin, during the early part of the Naknek, in the northern Great Plains area, there appeared an inundation of wide extent—the Logan sea—bringing in for a short time a North Pacific or boreal fauna distinguished by the ammonites *Cardioceras cordiforme* and *Cadoceras,* and the cephalopod *Belemnites densus.* The fauna is not a large one and consists mostly of bivalves, as *Pseudomonotis curta, Astarte packardi, Pleuromya subcompressa, Tancredia bulbosa, T. magna, Goniomya montanensis, Lima lata, Camptonectes bellistriatus, Gryphæa calceola nebrascensis,* and *Ostrea strigilecula;* also the ichthysaur *Baptanodon discus.* In the Great Plains region the formation has a thickness varying between 100 and 600 feet. In Wyoming it is known as the Sundance formation, and is correlated by Stanton[228] with the Oxfordian, "and perhaps the Callovian, in whole or in part." The latter, according to De Lapparent, is the base of the Upper Jurassic. The distribution of this fauna and sea was first mapped by Logan.[229]

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[227] Stanton and Martin: Bull. of the Geological Society of America, vol. 16, 1905.

The Great Plains submergence was of short duration, and vanished early in the Upper Jurassic before the Aucella fauna appeared in Alaska in the higher Naknek. This Upper Jurassic Aucella fauna is clearly of boreal origin and spreads south to California, "where it characterizes the Mariposa slate and equivalent formations, continuing through a great thickness of strata to the top of the Jurassic, and passing without any striking change into the Lower Cretaceous." The earlier Upper Jurassic of California "had a different, though imperfectly known, fauna more closely related to middle European faunas."[230]

During the later Upper Jurassic times elevation again set in with local volcanic activity, and the Pacific extensions were reduced to marginal seas. This movement was the introduction to the birth of the Sierra Nevadas.

Mexico.—Shortly after the retreat of the boreal or Logan sea all of eastern Mexico began to subside,—a region that, with the exception of the short and local Upper Triassic invasion, had apparently been land since the Proterozoic. This Mexican subsidence is correlated by Burckhardt[231] with the Kimmeridgian and Portlandian of the late Upper Jurassic. The faunas are unlike those of California and have decided southern European connections, since of the 85 species of ammonites described by Burckhardt[232] no less than 10 are identical with those of Central Europe (7), boreal Russia (1), and India (2). Boreal species present here are an abundance of *Aucella pallasi mexicana* and *Perisphinctes nikitini.* In addition, there are 11 other forms more or less closely related to forms of central Europe, showing that the Gulf of Mexico was in direct communication with the western end of the Mediterranean. Burckhardt states that in both areas "above the Lower Kimmeridgian there are deposits with a great development of *Haploceras filiar* and *Oppelia* of the group *O. flexuosa.* In the two regions the remarkable genus *Waagenia* also appears in the higher beds, and these in turn are overlaid, in Mexico as well as in France, by the zone with *Oppelia lithographica* and by the Lower Portlandian." It is probable that there was also slight and temporary communication with the Pacific ocean.

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[228] Stanton: Journal of Geology, 1909, p. 411.
[229] Logan: Journal of Geology, 1900, p. 245.
[230] Stanton: Journal of Geology, vol. 17, 1909, p. 412.
[231] Ibidem, 1909, p. 412.
[232] Burckhardt: Bol. 23, Instituto Geologico de Mexico, 1906.

Similar but very late Upper Jurassic faunas occur at Malone, Texas, and are described by Cragin.[233]

Continental deposits of the Great plains.—The Morrison formation, having a thickness of from 200 to 400 feet, has been placed on the late Upper Jurassic map (also on Early Comanchic map), yet the faunal evidence is equally as good, and even better, for regarding this, the Brontosaurus horizon, as Lower Comanchic. There are here no direct marine checks to fix the exact age of these deposits. They are, however, younger than Middle Jurassic and older than Washita, or the upper third of the Comanchic. According to Osborn, the mammals compare readily with those from the English Purbeck at the very top of the Jurassic, while the dinosaurs have long been regarded as Wealden in age, which Geikie and most European geologists refer to the Neocomian, equivalent to the lower part of the Comanchic.

From this formation there have been described several species of *Unio, Vivipara, Planorbis, Lioplacodes, Limnæa, Vorticifex,* and *Valvata.* According to C. A. White,[234] these fresh-water shells "of themselves offer no suggestion of greater age than the Tertiary." The more characteristic dinosaurs are: *Atlantosaurus, Apatosaurus, Brontosaurus, Diplodocus, Morosaurus, Stegosaurus, Camptosaurus,* and *Ceratosaurus.* Of the small Prototheria mammals may be mentioned: *Allodon, Ctenacodon, Stylacodon,* and *Diplocynodon.* Small cycad trunks also occur in the Upper Morrison (see further remarks on page 586).

Maryland.—In eastern North America the lower basal part of the Potomac series—that is, the Patuxent-Arundel—is often referred to the Upper Jurassic. Berry has restudied the floral evidence and regards these continental deposits as of Comanchic time. On the other hand, Lull, from the evidence of the dinosaurs, finds the facts in harmony with the age of the Morrison and Wealden. While as yet the proper systemic reference of the Morrison and the Patuxent-Arundel is still unsettled, the tendency is to refer both to the Lower Comanchic (also see page 586).

Arctic Alaska.—A very thick series of continental deposits of Upper Jurassic age was discovered by Collier[235] in the Cape Lisburne region of Alaska. The series has a thickness of about 15,000 feet, in which there are 39 low grade non-coking coal beds, varying in depth from a few inches to 30 feet. The total thickness of all the coal seen is 137 feet. The plants indicate Upper Jurassic age, but not so young as Wealden.

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[233] Cragin: Bull. no. 266, U. S. Geological Survey, 1905.

[234] White: Bull. no. 29, U. S. Geological Survey, 1886; see also Stanton, Journal of Geology, vol. 18, 1905, pp. 657-669.

[235] Collier: Bull. no. 278, U. S. Geological Survey, 1906.

On Prince Patricks land (latitude 76° 20′ north, longitude 117° 20′ west) were found the marine fossils *Harpoceras macclintocki* and *Monotis septentrionalis.* On North Cornwall (latitude 77° 30′ north, longitude 95° west) Belcher found vertebræ of *Ichthyosaurus.*

Comanchic Period

See plates 91 to 93

The highly emergent condition of the North American continent continued into the Comanchic, and the only marine areas of this time were the widely extended formations in the Gulf of Mexico region and the restricted series along the Pacific. Continental deposits devoid of marine fossils occur in a limited area along the Atlantic Piedmont, but sediments of this nature with a far greater distribution are present in the northern Great Plains region and extend into Canada.[236]

Table of Texas Comanchic Formations

- Washita series:
    - Buda.
    - Denison (Del Rio).
    - Fort Worth.
    - Preston.
- Fredericksburg series:
    - Edwards.
    - Comanche Peak.
    - Walnut.
- Trinity series:
    - Paluxy.
    - Glen Rose.
    - Travis Peak.

Gulf of Mexico area.—From Arkansas to southern Mexico occurs the greater development of the Comanchic or the "Lower Cretaceous." The Comanche series was defined by Hill to embrace his Trinity, Fredericksburg, and Washita divisions. In central Texas the thickness of these deposits is about 1,500 feet, which increases to 4,000 feet of limestone to the southwest of Chihuahua, and is said to attain far greater depth in central Mexico.[237]

Aguilera[238] divides the entire Mexican "Cretaceous" into Eo, Meso, and Neocretaceous, because the series, being devoid of recognizable breaks in sedimentation, is seemingly a continuous one. The Eocretaceous of Mexico is not yet characterized paleontologically, but is thought to represent the Neocomian, Barremian, and Aptian of southern Europe. A good section may be studied in the region of Zapotitlan and San Juan Ryan. In the Mesocretaceous, Aguilera includes the Mexican equivalents of the Albian and Cenomanian. The Washita is sometimes correlated with the Cenomanian, which is at the base of the European Upper Cretaceous, and Stanton informs the writer that he regards the Upper Washita as probably of Cenomanian time.

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[236] For a digest of the literature up to 1890, see White: Bull. no. 82, U. S. Geological Survey, 1891.

[237] Hill: Bull. of the Geological Society of America, vol. 5, 1893, pp. 297-338.

[238] Aguilera: Guide International Geological Congress, Mexico, 1906.

The Comanchic faunas are mainly from calcareous sediments, and are distinctly Mediterranean or southern European (especially Portugal and Spain) in type. The echinoids present "a very familiar facies to a European echinologist. . . . Several species are common European forms." Out of six forms from Mexico described by Cotteau, "three are characteristic of the European Lower Cretaceous (Aptian and Urgonian), namely, *Diplopodia malbosi, Salenia prestensis,* and *Pseudocidaris saussurei.*"[239] There is nothing in common with the decidedly different faunas of the Pacific border region of America. Each province develops distinct faunas out of the previous Jurassic assemblage.[240] For this reason C. A. White and Stanton[241] assume a complete land barrier along the Pacific, from California to South America, during the Comanchic.

The oldest Comanchic fauna, and one that the Mexican geologists regard as older than the Trinity, occurs at Tehuacan, Mexico. It is a fauna of reef corals and thick-shelled mollusks. Some of the common corals are: *Cryptocœnia* cf. *neocomiensis, Phyllocœnia cyclops,* and *Eugyra cotteaui.* There are also present the echinoid *Pseudocidaris saussurei* and the mollusks *Fimbria corrugata ?, Ostrea acuticosta, Trigonia plicatocostata, Cryptogervilleia, Glauconia bustamentii, G. cingulata, Nerinea* cf. *loculata,* and *Trachynerita nysti.*

Stanton[242] states that the Trinity has the foraminifer *Orbitolina* and the following characteristic Mollusca: *Trigonia stolleyi, T. crenulata, T. lerchi, Requienia* cf. *texana, Monopleura* cf. *marcida, M.* cf. *pinguiscula, Natica pedernalis, Glauconia, branneri, G.* cf. *helvetica,* and *G.* cf. *picteti.*

The Fredericksburg, the time of greatest inundation, is marked by the first abundance of *Gryphæa* (several species formerly referred to *G. pitcheri*) and *Exogyra.* In the Lower Fredericksburg there are forms of *Enallaster, Hemiaster, Epiaster, Holectypus, Schlœnbachia acutocarinata,* and *S. trinitensis.* In the upper part of the Fredericksburg the fauna of the southern region (Texas-Mexico) is in the main composed of *Requi-*

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[239] Gregory: Bull. of the Geological Society of America, vol. 3, 1892.

[240] Stanton: Journal of Geology, vol. 5, 1897, pp. 579-624.

[241] Stanton: Ibid., 1909, p. 417.

[242] Ibid., 1897.

enia, Monopleura, Radiolites, Nerinea, and corals, thus resembling that of the "Schrattenkalk" of the Urgonian.

The Washita continues the Fredericksburg fauna, but the characteristic species are *Pachydiscus brazoensis, Hamites fremonti, Schlœnbachia* of the type *S. inflata,* and *Turrilites brazoensis.* The Upper Washita is considered basal Cretacic, and is so represented on the paleogeographic maps.

Pacific area.—In California Comanchic, or, rather, Shastan, time began with the Knoxville, a somewhat restricted marginal invasion with boreal or Aucella faunas. It was in the Upper Knoxville that more extensive inundation took place to the north of the Sierra Nevada uplift—that is, it extended widely across Alaska, connecting the Pacific with the Arctic ocean. At the same time much of British Columbia was marginally invaded by the sea with a boreal fauna distinguished by *Aucella crassicollis.* At the close of the Knoxville, Alaska was again above the sea, thus shutting out the boreal waters with their northern faunas. In California the Knoxville has a thickness of from 12,000 to 20,000 feet. On Queen Charlotte islands the depth of divisions C, D, and E, referred to the Shastan, seems to be nearly 9,000 feet.

According to Stanton,[243] the fauna of the Knoxville is especially marked by an abundance of *Aucella piochii* in the lower beds and *A. crassicollis* in the upper 2,000 feet. He states that they are "so abundant that they must have actually monopolized the sea bottom." Among Mollusca the Turbinidæ are noteworthy. The more characteristic ammonites are: *Phylloceras knoxvillensis, Desmoceras californicum, Olcostephanus mutabilis, Hoplites hyatti, H. storrsi, H. angulatus, H. crassiplicatus,* and *H. dilleri.* These faunas are correlated with the Neocomian.

The faunas of the higher Shastan series or the Horsetown are at first much like those of the Knoxville, but the great changes in Alaska brought about by shutting out the boreal waters soon allowed the introduction of the Mediterranean faunas. As a whole, the Horsetown fauna is remarkably distinct from that of the Knoxville, and the former can usually be identified by the absence of Aucella. In its typical development this fauna, however, is restricted to northern California and Oregon, but late Horsetown time is represented as far north as Queen Charlotte islands.

> "Toward the close of the Horsetown the fauna was greatly modified by the introduction of many types that show relationship with the Cretaceous faunas of southern India, and also with those of Japan. This relationship was continued in the succeeding Upper Cretaceous faunas to such an extent that it is appropriate to speak of an Indo-Pacific province or region."[244]

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[243] Ibid., 1897.

[244] Stanton: Ibid., 1909, p. 415.

In the Lower Horsetown the following are the more distinctive forms: *Trigonia æquicostata* (also in Upper Horsetown), *Phylloceras onoense, Hoplites remondi, Olcostephanus traski, Desmoceras hoffmani* (also Upper Horsetown), *Crioceras percostatus,* and *Ancyloceras remondi.* In the Upper Horsetown, among other forms occur *Ancyloceras lineatus, Haploceras breweri, Lytoceras sacya,* and *Schlœnbachia inflata.* The Horsetown is correlated with the Aptian and Gault. Locally it seems to be deficient in continuous deposits into the higher Chico (Upper Cretacic), but Stanton regards this time break as of short duration. At least 10 of the Upper Horsetown species pass into the Chico of Cretacic time.[245]

Continental deposits.—In eastern North America there are no marine Comanchic strata. The Potomac series is fluviatile or fresh water in character. The lower and thinner division, or the Patuxent-Arundel, is often correlated with the Morrison, which is generally referred to the late Jurassic or Wealden (see the Jurassic chapter). Berry has informed the writer that the Arundel is only a different phase of the Patuxent. The former lies unconformably upon the latter, but no marked value should be placed on this physical feature because of the fluviatile character of the formations. Furthermore, the iron-ore bearing Arundel is almost restricted to the region between Baltimore and Washington, and the plants are those of the Patuxent. Besides large cycads, the Arundel has yielded dinosaur bones pertaining to *Pleurocœlus nanus, P. altus, Priconodon crassus, Allosaurus medius,* and *Cœlurus medius.* The dinosaur remains are in harmony with those of the Morrison and Wealden, and according to present evidence these deposits are as well, or even better, placed in the Comanchic (also see page 582).

The higher division of the Potomac series is known as the Patapsco, having a rich flora in which the angiosperms originate. This flora, however, is still mainly ancient in aspect—that is, it consists chiefly of ferns, cycads, and conifers. The angiosperms do not become dominant until the Raritan and Dakota of the Cretacic.

In the northern Great Plains area are other fluviatile beds, first described by G. M. Dawson as the Kootenai formation of Alberta. The thickness is given as about 4,700 feet, yet in Montana it is less than 600 feet. Locally it is coal bearing, there being in Alberta 22 workable coal beds. The small flora may be compared with the Lower Potomac. There are also a few Unios and fresh-water gastropods, "mostly of simple modern types."

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[245] Diller and Stanton: Bull. of the Geological Society of America, vol. 5, 1894, pp. 435-464.

In the Black Hills and in Wyoming are other continental deposits known as the Lakota, Cloverly, and Fuson. In the Black Hills area about 1,000 large cycad trunks have been unearthed; these are larger than those from the Patuxent of Maryland, but nearer them in development than the smaller ones from the Morrison of the Freeze Out hills of Wyoming. Knowlton informs the writer that these plant-bearing horizons practically have one flora, which corresponds best with the Wealden of Europe. It is closely linked with the Jurassic floras, as both have the same general aspect and a number of species are common to the two floras.

Cretacic Period

See plates 94 and 95

The widely emergent condition of the North American continent during the greater part of the Mesozoic was changed in the Cretacic. In the Comanchic most of Mexico was beneath the sea, and much of its eastern border so remained in the Cretacic, but here the invasion was far less than before. The decided submergence of Cretacic time began with the Dakota in the Gulf of Mexico area and spread north to the Arctic ocean east of the Rocky mountains. This formed the great Coloradoan sea, a syncline which with continental deposits first made its appearance certainly as early as late Triassic time and was apparently due to the thrusting of the Pacific border region during the early Mesozoic. The faunas of this province are linked with those of the Gulf area and the Atlantic border, but the last two regions have far more in common than either has with the Coloradoan sea. The waters of the Gulf border and the Coloradoan sea came into existence far earlier than the Atlantic overlap. A widely divergent faunal province occurs along the Pacific border from Lower California to Alaska. There were therefore two very distinct faunal provinces, and the one of the Atlantic is readily divisible into three subprovinces—the Coloradoan sea, the Gulf of Mexico region, and the Atlantic border, the latter being most typical in New Jersey and Maryland.

Throughout the Cretacic the Laramide range seems to have been in slight upward movement, with decided elevation toward the close of this period. The pressure coming from the Pacific folded the Cretacic deposits, which in places are 20,000 feet thick. As a result of this movement, North America was again greatly enlarged, and for a short time was connected with South America, thus permitting some intermigration of the land animals of the two continents.[248]

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[248] For a digest of the literature up to 1890, see White, Bull. no. 82, U. S. Geological Survey, 1891.

Table of Cretacic Formations

Colorado, Wyoming, and Montana			Western interior of Canada	Texas		Gulf coast	Atlantic coast
Break Laramie	Denver Arapahoe	Shoshone	(?) Paskapoo Edmonton				
				Break			Break
Pierre-Fox Hills	Bearpaw	Montana	Bearpaw (Odanah)				
	Judith River		Belly River	Navarro	Gulf series	Break	Jerseyian
	Claggett		Claggett (Melwood)			Ripley	
	Eagle			Taylor			Ripleyian
	Niobrara	Colorado	Niobrara	Austin		Selma Eutaw (Upper)	Raritan (Magothy)
	Benton		Benton	Eagle Ford		Break	Break
	(Bear River)						
	Dakota		Dakota	Woodbine			
	Break		Break	Break			

Mexico.—In Mexico the late Comanchic or Washita submergence continued unbroken into the Neocretaceous, according to the Mexican geologists. An extensive and well exposed section may be studied along the line of railway between Cardenas and Las Canoas, going east from San Luis Potosi to Tampico. Here, according to Böse,[249] the Cardenas limestone has an approximate thickness of 1,800 feet. He correlates this limestone with the Lower Senonian of Europe, and states that it rests on the Turonian or their Mesocretaceous. The former fauna holds the horizon of the American Lower Montana, or, better, the Ripleyan. In the basal portion of the Cardenas formation are the Gryphæa beds, with *G. vesicularis, Exogyra costata,* and *Ostrea aguileræ.* Higher up occurs the Orbitoides limestone, with *Ostrea* cf. *goldfussi, Inoceramus* cf. *crispii,* and corals. The upper member is the Coralliochama limestone, with *C. boehmi, Radiolites austinensis, Biradiolites* (3 species), *Exogyra costata, Ostrea glabra, Anomia argentaria, A. gryphorhynchus,* and abundance of *Actæonella,* and corals. These faunas appear to be related to those of the lower division of the Blue Mountain series of Jamaica.

Böse states that the Cardenas faunas are

> "in intimate relation with those of Europe, and especially with those having the mediterranean facies [as those of Gosau], but to it have been added some types of the fauna of the North. As already stated, however, our faunas are not always identical with those of Europe, but generally they are somewhat distinct in character; there must have been a relatively rapid migration from

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[249] Böse: Bol. 24, Instituto Geologico de Mexico, 1906.

Europe to America, and as all our species lived near the coast this migration should have been effected largely by means of a continent or a series of islands, instead of the present Atlantic; perhaps a study of the fauna of Jamaica will demonstrate later that that place was one of the stations on the road over which the animals came.

"In Europe the Gosau strata represent a mediterranean facies, and are notably distinguished in their paleontological character from the Senonian of the north of Europe. In America we observe a surprising analogous circumstance. We have known for some time that the Cenomanian strata of Mexico and Texas represent a mediterranean facies, but the Senonian also represents an analogous facies in Mexico (and Jamaica ?). In northern United States—that is to say, in New Jersey—is found, according to Credner, a facies of the Senonian which corresponds closely with that of the northern part of Europe; on the other hand, the fauna described in this work represents a facies which corresponds fairly well with that of Gosau, in the way that the facies of the Senonian of northern America corresponds with that of the north of Europe."

The Cardenas fauna has little in common with the Cretacic of the United States. Of the Colorado, there is present *Inoceramus labiatus, I. fragilis,* and *I.* cf. *simpsoni* (also in Montana series), and of the Montana *Ostrea glabra, Anomia argentaria, A. gryphorhynchus, Gryphæa vesicularis,* and *Exogyra costata.* The wide differences between the Cretacic of Mexico and that of the United States may be due in part to the decided limestone facies of the former region and perhaps more to latitude.

The Colorado or Turonian faunal equivalents of Mexico have as yet not been described, other than the few forms mentioned above.

Antilles.—On Jamaica, the oldest fossiliferous formations are those of the Blue Mountain series of about 5,000 feet thickness, with the base not seen. The Lower Division is Cretacic, while the Upper Division, or Richmond beds, is of Eocene age, according to Hill.[250] There are tuffs with some hard limestones and yellow clay, but most of the material "can be traced to igneous rocks," deposits of a shallow sea, a "tangled series of tuffs and conglomerates."

In the lower part of the Lower Division the dominant fossils are rudistids, *Actæonella,* and corals. The corals which have been described are: *Cladocera jamaicensis, Diploria conferticostata, Multicolumnastræa cyathiformis, Cyathoseris haidingeri, Porites reussiana,* and *Leptophyllia agassizi.* Of rudistids, there are *Barrettia moniliformis, Radiolites* (5 species), *Caprina jamaicensis, Caprinella quadrangularis, C. occidentalis,* and *C. gigantea.* Some of the rudistids are said to occur in the Upper

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[250] Hill: Bull. of Museum of Comparative Zoology, vol. 34, 1899; also see Gregory, Quarterly Journal of the Geological Society of London, 1895, pp. 255-310.

Division, associated with Eocene fossils (ibid., 129). It is probable that the Blue Mountain series is also present on Haiti, Costa Rica, and Cuba.

Apparently the same fauna occurs in northern Guatemala. Sapper[251] mentions *Barrettia* and *Sphærulites.* The formation consists of limestones, dolomite, limestone breccias, and gypsum, with some salt.

The Comanchic echinoids of the Antillean-Mexican region, as has been seen, are very closely related to those of southern Europe, but in the Cretacic "the two faunas developed on independent lines." This differentiation of the echinoids of the two areas continued into the Cenozoic.[252]

Colorado series.—The vast area east of the Rocky mountains, from Colorado to the Arctic ocean, which remained elevated throughout the Mesozoic, began to be invaded by the ocean during the early Cretacic. The southern Comanchic submergence had mainly vanished, and early in Dakota time the Gulf again spread toward the north. The submergence thus begun was continued northward rapidly during the Benton, and it is quite likely that at about the same time the Arctic extended southward and united with these southern waters. This, then, was the great inland Coloradoan sea, with its deposits resting unconformably upon various of the earlier formations.

The Dakota fauna, as published, is a small one of brackish-water forms and Unios, with a few marine species. Stanton[253] states that "the fresh-water species show relationship through the genus *Pyrgulifera* with the fauna of the Bear River formation, which is apparently about on the horizon of or a little later than the Dakota. The Bear River fauna of C. A. White[254] "is unique among western non-marine faunas in that it contains a number of types that have left no descendants in later formations of the region." The flora of the Dakota has over 500 species, the angiosperms being dominant throughout all the horizons.

Succeeding the Dakota is the Colorado series, which is divided into a lower portion, the Benton, and an upper, the Niobrara, but not everywhere can this two-fold separation be maintained. The Colorado series is characterized by *Inoceramus labiatus,* and extends from the Gulf of Mexico probably to the Arctic ocean, yet in the Gulf area east of western Arkansas and along the Atlantic coast no deposits of this time are known. The diagnostic fossils of the Colorado are: *Inoceramus labiatus, I. dimidius, I. fragilis, I. deformis, I. undabundus, Ostrea lugubris, Exogyra*

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[251] Sapper: Petermann's Mittheilungen, Ergänzungsheft, 1894, p. 113.

[252] Gregory: Bull. of the Geological Society of America, vol. 3, 1902.

[253] Stanton: Journal of Geology, 1909.

[254] White: Bull. no. 128, U. S. Geological Survey. See also Stanton, American Journal of Science, vol. 43, 1892; Veatch, Professional Paper no. 56, U. S. Geological Survey, 1908.

columbella, Gryphæa newberryi, Gervillia propleura, Cardium pauperculum, Liopistha meeki, Glauconia coalvillensis, Pugnellus fusiformis, Baculites gracilis, Metoicoceras swallovi, Scaphites warreni, and the keeled ammonites *Prionotropis, Prionocyclus,* and *Mortoniceras.* The Colorado is also marked by the absence of *Heteroceras, Ptychoceras, Anisomyon,* large *Baculites,* and the broad compressed forms of *Inoceramus,* as *I. sagensis* and *I. vanuxemi.*[255]

The Niobrara chalk is typically developed only in eastern Colorado and Kansas, and thence northward into Manitoba. To the south it connects faunally through identical species with the Austin chalk of Texas, though in the latter formation the fauna is a larger and more varied one. To the west and northwest the Niobrara changes into shale, and it is then indistinguishable from the Benton, its fauna being here made up of Niobrara and Austin forms, Benton derivatives, and local species.

Montana series, western.—The Colorado series is followed without break by the Montana. The faunas of this series vary locally from typically marine to brackish and fresh-water deposits. The marine life is a continuation of that of the Colorado with the addition of Arctic and southern Atlantic migrants. Some of the more distinctive fossils are: *Anisomyon borealis, Inoceramus sagensis, I. sublævis, I. crispii, I. tenuilineatus, I. vanuxemi, Ostrea pellucida, Veniella humilis, Gervillia subtortuosa, Callista deweyi, Breviarca exigua, Mactra gracilis, Corbulamella gregaria, Amauropsis paludinæformis, Anchura nebrascensis, Fasciolaria cretacea, Scaphites conradi, S. nodosus, Placenticeras intercalare, P. whitfieldi, Baculites ovatus, B. compressus, B. grandis, Heteroceras,* and *Ptychoceras.*

The lower part of the Montana series or, rather, the Pierre formation (Claggett and equivalents) is nearly everywhere typically marine, but in the western area of the Coloradoan sea, from central New Mexico into southern Athabasca, there is more or less alternation of coal-bearing brackish and fresh-water beds with local marine horizons. These in part are the Judith River-Belly River beds and the Mesaverde formation, unknown in the eastern area of the Coloradoan sea. Above this series, in the Bearpaw and equivalent formations, the marine deposits are again more widespread in the Montana. The invertebrates "fall into three general categories of marine, brackish-water, and fresh-water forms, the latter including a few more or less doubtful land shells." The brackish-water fauna contains *Ostrea, Mytilus, Modiola, Anomia, Corbicula, Panopœa,*

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[255] Stanton: Bull. no. 106, U. S. Geological Survey, 1893, and Journal of Geology, 1909, p. 419.

Rhytophorus, and *Goniobasis.* As a rule, the fresh-water forms are found in distinct beds associated with land mollusks and land vertebrates. The vertebrate life is very varied, but is largely composed of fragmentary material, in the main of turtles and dinosaurs. "When considered in its entirety, the vertebrate fauna of these beds is remarkably similar to, though distinctly more primitive than, that of the Laramie. Almost or quite all of the Laramie types of vertebrates are present, though, as a rule, they are represented by smaller and more primitive forms."[256]

Eastern and southern or Ripley faunas of Montana time.—Weller[257] has recently redescribed the northern Ripleyian and Jerseyian faunas, consisting of about 600 forms. He states that "a considerable number of species have an extraterritorial distribution, and by far the larger number of these species which occur outside of New Jersey are known from the Upper Cretaceous formations of the Gulf-border region, in the Ripley and associated formations of Alabama, Mississippi, Texas, etc." The relationship with the Montana is also close, but less than that of the Gulf border.

Along the Atlantic border the Ripley faunas are introduced by deposits largely continental in character, which finally pass into marine beds. These are the Raritan-Magothy formations, with a flora of about 150 species. The marine faunas of these beds are small and rather of brackish-water types. The Tuscaloosa and Tombigbee are also correlated with the Magothy.

In regard to the Ripley fauna, Stanton[258] presents the following summary:

> "Toward the south in New Mexico the littoral facies of the Montana fauna blends with the Ripley fauna, which is well developed in the latest Cretaceous formations of Texas, Mississippi, Alabama, and throughout the Atlantic coastal plain to New Jersey. The Ripley and Montana faunas have many species in common. . . . In the Montana fauna the genus Inoceramus is very abundant and varied, and ammonoids—especially Placenticeras, Baculites, Scaphites, and other evolute types—are abundant, while the Ostreidæ, Veneridæ, Cardiidæ, etc., and many types of gasteropoda, including Volutidæ, are greatly developed. The Ripley fauna is more varied and luxuriant, so to speak, than the Montana and apparently indicates a warmer, or at least a more favorable climate. . . . The Montana fauna probably received some of its elements directly from the Arctic, while the Ripley fauna came in from the Gulf of Mexico and the Atlantic. With the connection between the Atlantic and Pacific closed in the Mexican and Central American region as at present, the Gulf stream would give similar conditions, and would distribute the Ripley fauna

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[256] Stanton and Hatcher: Bull. no. 257, U. S. Geological Survey, 1905.

[257] Weller: Geological Survey of New Jersey, vol. 4, 1907.

[258] Stanton: Journal of Geology, vol. 17, 1909, p. 421.

along the coast from Texas to New Jersey. It is noteworthy that the European fauna most closely related to the Ripley is found at Aachen in [northern] Germany."

Pacific coast.—In California the Horsetown of Comanchic age passes without break into the littoral Chico of the Cretacic. Many of the species are common to the two formations. In northern California the Chico consists chiefly of sandstone and conglomerate, with local zones of shales, the whole attaining a thickness of 4,000 feet. Wallala and Lower Martinez are other names included in the Chico. Division A of the Queen Charlotte series and the Nanaimo series of Vancouver (5,226 feet thick; Comox, 4,912 feet) are the northern equivalents of the Chico, all three being united by a common fauna.[259] With the exception of *Gryphœa vesicularis, Inoceramus digitatus, I. labiatus* ?, and possibly a few other species of bivalves, there is nothing in common between the Pacific faunas and those of the Coloradoan sea. All these forms either have a long range or are widely distributed species. None of the Pacific coast faunas are thought to be younger than the Pierre, and the faunas of the next formation, or Tejon, suggest the Clairbornian of late Eocene time, but are usually regarded as basal Eocene. In some places the Chico and Tejon are disconformable with one another, but in general there is angular unconformity between them, showing that the Laramide revolution is as well indicated here as in the deposits of the Coloradoan sea.[260]

Some of the more characteristic fossils are: *Trigonia evansana, Cucullœa gravida, Pectunculus veatchi, Caryatis nitida, Pharella alta, Cymbophora ashburneri, Inoceramus whitneyi, Coralliochama orcutti, Actœon inornatus, Anchura californica, A. falciformis, Scobinella dilleri, Rostellites gabbi, Gyrodes expansa, G. conradiana, Pugnellus hamatus, Perissolax brevirostris, Acanthoceras turneri, Helicoceras* (?) *vermicularis, Pachydiscus newberryanus, Schlüteria jugalis, Schlœnbachia chicoensis,* and *Baculites chicoensis.*

Stanton[261] states that

> "No ammonoides have been found in any collections from the Tejon made since Gabb's time.
>
> "The affinities of our west coast Cretaceous faunas are much closer with those found on the opposite side of the Pacific, in southern India, Japan, and Saghalien, than with the Cretaceous faunas in the United States."

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[259] Whiteaves: Mesozoic fossils, Geological Survey of Canada, vol. 5, 1903; lists a fauna of 168 species, on pages 314-407.

[260] See Diller and Stanton: Bull. of the Geological Society of America, vol. 5, 1894. Stanton: Seventeenth Annual Report of the U. S. Geological Survey, part i, 1896, pp. 1011-1060. Merriam: Journal of Geology, vol. 5, 1897, pp. 757-775. Weaver: Bull. of the University of California, vol. 4, 1905, pp. 101-123.

[261] Stanton: Ibid., 1906, pp. 1031-1034.

The Chico is also present in Alaska (Lower Yukon and Alaska peninsula), but as yet very little is known of the marine fossils.[262]

The close of the Cretacic.[263]—The Laramie is the last of the conformable Cretacic series of the Coloradoan sea. Its formations consist of alternations of brackish water and continental deposits. Stanton[264] states:

> "The brackish-water species have survived from earlier formations in the same region by living in the marine waters or advancing with the sea margin when the submergence came. The fresh-water types must have been preserved in the streams of the adjacent lands when marine or even brackish waters covered the larger part of their habitat. A considerable number of fresh-water types were thus enabled to survive into the Tertiary. . . . With the brackish-water forms of the Laramie the case is different. . . . In areas of non-marine deposition where the line between Cretaceous and Eocene has not been sharply drawn, because the erosion plane that is supposed to separate them has not yet been located, the occurrence of an oyster bed, or a stratum full of Corbula, is sufficient evidence that the rocks are still Cretaceous and below the major unconformity that separates Cretaceous from Tertiary."

During the past few years a discussion has been going on among stratigraphers, in which the opinions centering around "What is the Laramie?" and "The systemic age of the Ceratops beds" differ considerably. In the field, geologists have pointed out erosional unconformities which they believe to be of wide extent and of the greatest importance as representing an interval of long duration. The strata above this unconformity are said to contain the Fort Union flora of Eocene age, and also the well known Ceratops fauna of dinosaurs associated with archaic mammals. Geologists therefore maintain that these formations are basal Eocene, and that the distinctive Cretacic land animals persisted into Eocene time or the Lower Fort Union, but were soon and almost suddenly extinguished in the Upper Fort Union in Colorado, Wyoming, and Montana.

Throughout a large area in Wyoming and Montana the latest marine Cretacic strata of this region are overlain by a formation that is not typically marine, composed of light colored sandstones and darker sandy shales. This formation has been called "Ceratops beds of Converse county," "Lance Creek beds," "Hell Creek beds," "Laramie," etcetera.

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[262] Stanton and Martin: Bull. of the Geological Society of America, vol. 16, 1905, pp. 408-409.

[263] The literature on this subject is as follows: Cross: Proceedings of the Washington Academy of Sciences, vol. 11, 1909, pp. 27-45. This paper gives references to all others bearing upon this discussion. Knowlton: Ibid., 1909, pp. 179-238. Stanton: Ibid., 1909, pp. 239-293. Hatcher and Lull: Monograph 49, U. S. Geological Survey, 1907. Brown: Bull. of the American Museum of Natural History, vol. 23, 1907, pp. 823-845.

[264] Stanton: Journal of Geology, vol. 17, 1909, p. 423.

The floral evidence has recently been summed up by Knowlton, who refers the Ceratops beds to the Lower Fort Union of Tertiary age. He states:

> "It is shown that the lower member rests, in some cases unconformably, in others in apparent conformity, on the Fox hills or Pierre, and the conclusion is reached that an erosional interval is indicated during which the Laramie—if ever present—and other Cretaceous and early Tertiary sediments were removed.
>
> "It is shown that the beds under consideration, being above an unconformity, can no longer be considered as a part of the 'conformable Cretaceous series,' and hence are not Laramie.
>
> "The final conclusion is reached that the beds here considered ('Hell Creek beds,' 'somber beds,' 'Ceratops beds,' 'Laramie' of many writers) are stratigraphically, structurally, and paleontologically inseparable from the Fort Union, and are Eocene in age" (237, 238).

Stanton has reviewed the stratigraphy and paleontology of these beds from another standpoint, with the result that "the Ceratops beds are of Cretaceous age." His evidence sums up as follows:

> "The 'Ceratops beds' with the Triceratops fauna are always pretty closely associated with the uppermost marine Cretaceous strata or are separated from them by transitional brackish-water beds. They are always overlain by a thick series of rocks containing a Fort Union flora in which no dinosaurs have been found, and in the Fish Creek, Montana, region this overlying series also contains primitive mammals related to those of the Puerco and Torrejon faunas.
>
> "Throughout a large part of the area no evidence of an unconformity beneath the 'Ceratops beds' has been found, while higher in the section unconformities have been demonstrated or suggested at a number of places. Unconformities have been reported below the 'Ceratops beds' on Hell creek, Montana, on the Little Missouri in North Dakota, and in Weston county, Wyoming, but in none of these cases has any proof been furnished that the erosion interval is important [279]. . . .
>
> "Soon after the Benton, however, large areas west of the Front Range in Colorado and Wyoming and west of the 108th meridian in Montana previously covered by the sea began to emerge, either by uplift or by filling of the basins with sediment, and as they came up to sealevel or a few feet above it land and marsh flats became established and all the conditions became favorable for the formation of coal beds. Land animals also came in and the streams and fresh-water lagoons received their appropriate population from adjacent areas, while the bays and estuaries were inhabited by brackish-water forms. . . . The neighboring land-masses must have formed large areas and have had considerable elevation in order to furnish the immense thickness of Upper Cretaceous sediments known in this region (280).
>
> "There were oscillations, so that occasional brackish-water or marine deposits were brought above those of land and fresh-water origin, and it is probable that these oscillations were not always synchronous throughout the region. . . . Locally, as in part of Bighorn Basin, this non-marine sedimentation may have been almost continuous until the end of the Cretaceous, but over most of the area there was a more important subsidence which brought the marine sedi-

ments represented by the Lewis and Bearpaw shales over the coal-bearing formations.

"As far up in the series as brackish-water fossils are found they occur in usually thin beds intercalated amongst the fresh-water strata, showing that the two elements of the fauna had separate habitats. . . . These mollusks evidently lived in tidal waters connected somewhere with the open ocean" (281, 282).

The most interesting biological side of the question connected with these beds is of course furnished by the wonderful dinosaur assemblage, among which the Ceratopsia are the more conspicuous because more commonly found. These forms have been well described by Hatcher and Lull. The dinosaurs represented are: *Triceratops horridus, T. flabellatus, T. prorsus, T. serratus, T. sulcatus, T. obtusus, T. elatus, T. brevicornis, T. calicornis, Diceratops hatcheri, Torosaurus latus,* and *T. gladius,* as well as *Trachodon, Tyrannosaurus rex,* and *Ornithomimus.* The mammal remains are very fragmentary, and all pertain to archaic forms—that is, Mesozoic types—which also range into the basal Eocene beds. The dinosaurs, however, are as yet not known to range above the Cretacic.

The fresh-water mollusks are varied, the fauna consisting of about 25 named species of *Unio,* together with *Anodonta, Sphærium, Corbicula subelliptica, Viviparus, Tulotoma thompsoni, Campeloma* (several species), *Thaumastus, Goniobasis tenuicarinata, Physa, Helix, Limnea,* and *Bulimus.* This fauna is quite distinct from all those of the same habitat which succeed it in the American Eocene.

The brackish-water faunas have *Ostrea subtrigonalis, O. glabra, Corbula subtrigonalis, C. undifera, Corbicula cytheriformis, C. subelliptica, C. occidentalis, C. fracta, Anomia micronema, Neritina baptista, N. volvilineata, Melania wyomingensis.* These are likewise Cretacic forms.

Of land plants, in Converse county alone are 48 named species, of which 5 are figs and 2 are palms. The flora indicates a subtropical climate. In this connection it should be stated that the floras of the late Cretacic and Eocene show no marked differences, the change being one of species, not of different families and genera (information supplied by Knowlton).

The vertebrate evidence shows close relationship with that of the Judith River fauna, which is known to be Cretacic, and lies beneath a thousand feet or more of marine Cretacic beds. The whole fauna of the Ceratopsia beds is decidedly Cretacic, and there is nothing to suggest the Cenozoic unless it be the archaic mammals, of which two or three genera are also known in the Torrejon (Eocene), where the mammals, and those of the Puerco (Eocene) as well, are all of Mesozoic origin.

The fresh-water fauna is composed of existing genera, which in themselves are not of much stratigraphic value. Taken in connection with the local stratigraphic sections in which they occur, however, it is seen that the formations are intimately bound with those of unmistakable Cretacic age. Again, the Unios are unlike those of the Eocene in that the umbos of the shell are often sculptured. The brackish-water faunas are certainly those of the marine Cretacic, and the succession shows that these finally vanish from the interior region, the Cretacic series going over completely into fresh-water beds of a continental character. Nowhere has the marine Tertiary entered this region, and the nearest Eocene sea did not advance beyond Tennessee or coastal Texas.

Stanton concludes:

> "The 'Ceratops beds' are of Cretaceous age as decided by stratigraphic relations, by the pronounced Mesozoic character of the vertebrate fauna with absence of all Tertiary types, and by the close relations of its invertebrate fauna with the Cretaceous. The relations of the flora with Eocene floras is believed to be less important than this faunal and stratigraphic evidence. Taken in their whole areal extent they probably include equivalents of the Laramie, Arapahoe, and Denver formations of the Denver Basin."
>
> "The Fort Union formation, properly restricted, is of early Eocene age, the determination resting chiefly on its stratigraphic position and its primitive mammalian fauna which is related to the earliest Eocene fauna of Europe. The very modern character of the flora tends to confirm the correlation" (293).

TERTIARY OR NEOZOIC (CENOZOIC) ERA

See plates 96 to 100

Familiarity at first hand with the Tertiary formations requires a vast amount of detailed knowledge of the plants and land animals, and especially of the marine invertebrates, which the writer does not possess. In order to make the paleogeography of North America as complete as possible, however, he has devoted his efforts toward the compilation of the maps and the table of formations more for the benefit of teachers of historical geology than for stratigraphers. With the maps he has had the assistance of Dall, Arnold, and Vaughan.

The more important literature pertaining to this era is as follows:

Dall and Harris: Correlation papers—Neocene. Bulletin 84, U. S. Geological Survey, 1892.

Dall: A table of the North American Tertiary horizons, etc. Eighteenth Annual Report of the U. S. Geological Survey, 1898, pages 323-348. Contributions to the Tertiary fauna of Florida, parts I–VI, 1886-1903. Transactions of the Wagner Free Institution of Science, Philadelphia.

Table of Tertiary or

Period	Sub-period	Epoch	Middle Atlantic States	Gulf States	Pacific Coast
Neogenic	Pleistocene		Columbia { Talbot Wicomico Sunderland } Break	Columbia Cornfield Harbor	Kowak Ground ice San Pedro–Coos
	Pliocene		Lafayette Break	Lafayette Caloosahatchie–Croaton–Waccamaw	Merced–Paso Robles Mytilus–Deadman Island San Diego Purisima–Cholame
	Miocene		Duplin–Suffolk–Yorktown Chesapeake { Saint Marys Choptank–James River Calvert–Petersburg Shiloh }	Pascagoula Alum Bluff–Chesapeake	Upper { San Pablo–Snooke Empire Santa Margarita } Break Lower { Monterey (?Modelo) Vacqueros–Pasadena }
Eogenic	Oligocene	Appalachicolan	Absent	Oak Grove (Bowden of Jamaica) Chipola Chattahooche (Grand Gulf–Tampa)	San Lorenzo Tunnel Point Astoria Aturia
		Vicksburgian		Ocala Peninsular { Vicksburg Red Bluff }	Kenai of Alaska
	Eocene	Jacksonian	Absent	Zeuglodon–Santee Moodys Branch Marks Mill	
		Claibornian	Break Nanjemoy { Woodstock	Upper { White Bluff Claiborne } Lower { Ostrea sellæformis Lisbon Tallahatta }	Break
		Chickasawan	Potapaco } Aquia { Paspotansa Piscataway }	Upper { Hachetigbee Woods Bluff (Bashi) } Lower { Bells Landing (Tuscahoma) Greggs Landing Nanafalia }	? Little Falls Karquines { Tejon-Arago-in part Puget
		Midwayan	Break	Naheola Sucarnochee Midway	Upper Martinez–Puget Break }

Neozoic (Lyell) Formations

	Great Plains		Faunal Phase	Mammal Zones	European analogues, De Lapparent's Traité
	Sheridan–Rock Creek		Seventh	Champlain Glacial Equus	
	Loup River–Archer–Blanco		Sixth	Glyptotherium	Sicilian Astian Plaisancian
	Ogalalla–Clarendon	Mascall	Fifth	Protohippus–Procamelus	Sarmatian–Pontian
	Pawnee–Deep River			Ticholeptus	Helvetian–Tortonian
Arikaree	Gering–Monroe Harrison–Rose Bud	John Day	Fourth	Merycochœrus Diceratherium	Burgidalian
White River	Upper Brule			Leptauchenia Protoceras	Aquitanian
	Lower Brule			Oreodon–Metamynodon	Stampian (Tongrian)
	Chadron			Titanotherium	Sannoisian (Ligurian)
	Break		Third		
	Uinta			Diplacodon	Ludian Bartonian
	Washakie Bridger			Eobasileus Uintatherium	Lutetian
	Wind River–Green River–Huerfano			Orohippus Bathyopsis	Ypresian (Londinian)
Wahsatch	Knight Fowkes Almy		Second	Lambdotherium Coryphodon–Eohippus	Sparnacian
	Break		First		
Fort Union	Torejon Puerco			Pantolambda Polymastodon	Thanetian

Gregory: Contributions to the paleontology and physical geology of the West Indies. Quarterly Journal of the Geological Society of London, 1895, pages 255-310.

Clark: Correlation papers—Eocene. Bulletin 83, U. S. Geological Survey, 1891. Maryland Geological Survey, Eocene, 1901; Miocene, 1904; Pliocene and Pleistocene, 1906.

Osborn and Matthew: Cenozoic mammal horizons of western North America. Bulletin 361, U. S. Geological Survey, 1909.

Arnold: The Tertiary and Quaternary Pectens of California. Professional Paper 47, U. S. Geological Survey, 1906. Environment of the Tertiary faunas of the Pacific coast. Journal of Geology, 1909.

The new geologic Time Table

On the basis of the paleogeography here presented and the diastrophism postulated by these maps, two curves have been developed, showing the amount in square miles of the various inundations throughout geologic time since the beginning of the Cambric. The upper curve of the chart (plate 101) is based on the land area of the North American continent as at present emerged, which is estimated to be about 8,200,000 square miles in extent. Since vast areas of the continent are not well known geologically, it was thought that errors might occur which would be detected were another curve calculated for the region best known—that is, the United States and a part of southern Canada, or the area between 30° and 50° north latitude. The square mile content of this space is calculated to be a little more than 3,530,000, the fluctuating inundation of which area is illustrated by the lower curve of the chart. A comparison of these two curves shows that they are very much alike, but that the upper one based on the greater area has the nodal points far more accentuated than the lower one based on the smaller but better known area. It is therefore probable that no marked errors, such as additional periods or differently delimited periods, exist in regard to the North American continent.

In the chart the vertical lines or abscissæ are 80 in number, representing 57 different paleogeographical maps (52 are here published) and 23 other time divisions. These are named in the lower part of the chart, and according to the present acceptance of them are grouped in periods or systems and eras. For the 57 maps, the amount of inundation is that calculated from these maps, while for the other time divisions the amount is estimated. In the former case the lines of the plotted curves are drawn straight, and in the second instance they are wavy. The time ratios are based on Dana's estimates somewhat changed, giving 12 to the Paleozoic, 6 to the Mesozoic, and 2 to the Tertiary. The time in years is practically based on Walcott's estimate of 1894 (Proceedings of the American

Association for the Advancement of Science). It will be seen that much more time has been allowed the Cambrian and Ordovician than is usually assigned them; together they are allotted 43 per cent of the Paleozoic era. The per cent of time for each period is stated throughout, but it should be noted that these are rough estimates and not calculations based on the known thickness of the formations composing the periods or systems. The great length of Triassic time is based on the long and nearly complete Mediterranean record.

The horizontal lines or ordinates numbered 1 to 8 on the chart each represent one million square miles of the North American continent. The two other horizontal lines give the areas for the "United States" and "North America" as explained above; hence the extent of the inundations illustrated by the curves may be seen at a glance in relation to present conditions.

A detailed analysis of these curves shows that there have been 17 lows, or inundations, separated from one another by as many highs, or emergent periods. Of these, 11 are Paleozoic, 4 Mesozoic, and 2 Tertiary. For easy reference, these are arranged in the following table, the amount of area submerged being given in square miles, with the percentage. The names in italics represent the marked submergences, 10 of which reach over 20 per cent.

Table of North American Inundations

Present land area of North America, about 8,200,000 square miles.			Present land area of North America between 30° and 50° north latitude, about 3,530,000 square miles.		
Time of greatest inundations.	In square miles.	In per cent.	Time of greatest inundations.	In square miles.	In per cent.
Middle Georgic	1,451,000	17.6	Middle Georgic	421.000	12.0
Middle Acadic	2,587,000	31.6	*Middle Acadic*	1,648.000	46.7
Middle Ozarkic	1,775,000	21.7	*Middle Ozarkic*	1.016.000	28 9
Beekmantown	1,663,000	22 7	*Beekmantown*	1,065,000	30.3
Early Trenton	4,676,000	57.2	*Early Trenton*	2,158,000	61.2
Late Richmond	3,340.000	40.0	*Late Richmond*	1,560,000	44.3
Louisville	2,940.000	35.9	*Louisville*	1,246,000	35.7
Hamilton	2,881,000	35.2	*Hamilton*	1,126,000	32.0
Burlington	2,644,000	20.1	*Burlington*	874,000	24.8
Saint Louis	620,000	7.6	Saint Louis	348 000	10.0
Late Pottsvillian	2,270,000	27.7	*Late Pottsvillian*	1,283,000	36.4
Late Triassic	1,261,000	15.4	Late Triassic	292,000	8.4
Late Jurassic	1,130,000	13.8	Late Jurassic	646,000	18.4
Fredericksburg	1,559,000	19.0	Fredericksburg	433,000	12.4
Niobrara (estimated)	2,778,000	33.9	*Niobrara* (estimated)	1,354,000	41.3
Early Oligocene	236,000	2.9	Early Oligocene	154,000	4.5
Upper Miocene	360,000	4.4	Upper Miocene	234,000	6.7

Of the 17 submergences, 10 are marked ones, having inundated either of the two defined areas more than 20 per cent. In the Trenton the submergence covered about 60 per cent of North America. It is also seen that of these 10 decided submergences, 9 occurred during the Paleozoic, while the tenth took place during the close of the Mesozoic. The 7 smaller submergences inundated the areas from 2 to 19 per cent. The first of all these floods (Georgic) is classed in the so-called secondary inundations, and records the beginning of the Paleozoic. However, it is the most marked of the minor submergences, and is followed by 8 primary and successive inundations. Another minor flood (Saint Louis) then appears, which is succeeded by the last of the greater Paleozoic submergences. It may therefore be said that all the Paleozoic inundations except one (Saint Louis) are of the major type. Further, the Paleozoic submergences attain their maxima in the Ordovicic, each subsequent flood being of smaller extent. These facts seemingly furnish decisive indications that during the Paleozoic the oceanic areas had not yet attained their present abyssal depths, and that outside the eastern border region the North American continent was a low, featureless land-mass throughout this era. The slightest secular or aggradational change anywhere on the globe then affected the oceans more than at any later time, so that they readily flowed widely over the lands, thus developing the very shallow continental seas. In a general way, it may be said that the present broader relations of the oceanic areas to the lands have been fixed since the Appalachian revolution of the Atlantic realm.

It is becoming more and more apparent that the geologic chronology for the greater divisions must be based on criteria additional to those now in use. In chronology, dependence will always have to be placed primarily on the fossil content of the sediments. In correlating the more or less similar developments of the various faunal provinces, however, some physical basis is needed underlying the faunal likeness or dissimilarity. Such a principle apparently exists in the submergences or the positive changes of the strand-line, for when one of these attains its maximum of spread, the widest distribution of similar faunas and identical species would naturally be expected. Conversely, the maximum of emergence must mark the absence of faunas in most land areas, followed for a time by more or less dissimilar faunas in all the provinces.

As long ago as 1883, Suess concluded that the geologic time table would eventually be based on diastrophism and the faunal changes caused by these movements in their physical environment. He states: "It is the physical causes of faunal transformations which will, when once they are recognized, form the only true basis for a delimitation of chronological periods."[266] Diastrophism as determined by the successive faunas and their plotting on paleogeographic maps seems to include the physical principle that will not only render the formations of a province capable of being grouped into periods, but will serve as a fairly reliable guide for intercontinental correlations of like and unlike faunas as well. If the principles of diastrophism and paleogeography are to be made the basis for the future delimitation of periods or systems, the personal equation of workers in regard to the period value to be given this or that fossil or fauna is reduced to a minimum. In such a classification the disposition of a newly discovered horizon will adjust itself automatically on the basis of its paleogeography. If such maps can not be made, however, and the local conditions are not final, then temporary adjustment must of course be based on faunal affinity.

With these principles as a basis, the curve chart (plate 101) has been constructed, and from it may be seen that since the beginning of Paleozoic time there have been at least 17 inundations, and that these are separated from one another by an equal number of high nodal points or emergent periods. On the chart, therefore, a period or system embraces the time represented by the space between two high nodes of the curves, including one more or less long low, or inundation. This method has been used by the writer[267] since 1902, when he stated that "each system should begin with a subsidence and end with an emergence."

According to the geological text book of Chamberlin and Salisbury, the geologic column has 13 systems, if the Tertiary is divided into two periods, as is now generally the practice. From the chart herewith presented it is learned that there are 17 submergences, or lows, and it would seem, therefore, that the inherited classification is not borne out by the newer principles of paleogeography and diastrophism. A closer analysis of these curves, however, brings out the fact that in general the eras have hitherto been correctly defined, but that in detail the periods must be newly delimited in a number of places. The most marked of these changes is the division of the Cambrian and Ordovician each into three periods and the Mississippian into two periods. The bases for these major changes are described elsewhere in this work, while the new delimitation of the old periods is indicated at the top of the chart.

Of less importance are the following results: On the sole basis of the diastrophic curve for the "United States," it is still debatable whether the Siluric should close with the Manlius or with the Oriskany. During this entire time there was very little inundation, the small seas were oscillatory, and there was no decided positive or negative movement of the strand-line. An analysis of the upper curve, however, shows that the Manlius was the last formation of the Siluric, being the highest point of the emergence, and that while the strand-line during the Helderbergian and Oriskanian was positive, it was not markedly so until the Onondaga. Taking all the facts into consideration, however, this upper curve proves to be in harmony with the later views of the majority of European and American stratigraphers. The writer therefore regards the nodal point on this upper curve as the best expression of the more natural division between the Siluric and Devonic.

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[266] Antlitz der Erde, vol. 1, 1883; Sollas translation, vol. 1, p. 14.

[267] Ulrich and Schuchert: Report of the New York Paleontologist, 1902, p. 659.

During the past ten years the dividing line between the Devonic and the Mississippic has also been debatable in America, but the two curves of the chart, when considered in combination, unfortunately furnish no definite answer to the problem. The difference between the two curves is due to a lack of detailed knowledge as to the areal distribution of the Chemung and Bradfordian equivalents. The lower curve is thought to more nearly represent the truth than the upper one, in which the deposits of Bradfordian time fall into the Mississippic period. According to the upper curve, however, this epoch is Devonic, but not much dependence should be placed on this portion of the curve, for as yet this interval is practically unknown in the Cordilleran sea. Disregarding the minor ups and downs of the two curves, it may be seen that all the deposits from the base of the Helderbergian to the close of the Keokuk belong to one great diastrophic cycle. In the end this view may be found to be the correct one, but until more of the paleogeography of the world is deciphered nothing decisive can be said at this time. Should this view finally prevail, the term Mississippian will even then be found useful.

The new period Tennesseic is borne out by both curves, but is especially emphasized by the upper one. Neither curve, however, is thought to be expressive of the actual amount of inundation, because knowledge of the areal distribution of these deposits is as yet not exact. In any event, enough is known of these formations, of their faunas, and the diastrophism indicated by their areal spread, to denote a general movement, both negative and positive, of the strand-line.

Beginning with the Pottsvillian, the strand-line became decidedly positive throughout America, with its maximum at the close of this epoch. Then very slowly the tide turned, and there was continuous emergence to the close of the Permic. On this basis alone there is no

Permic cycle in America, and all the Coal Measures, including the Guadalupian, belong to one period. The determined chronology of these deposits, however, must be based upon European paleogeography of these formations. It must therefore be understood that the dividing line on the chart between the Pennsylvanic and the Permic is hypothetical, being based on a supposedly correct interpretation of the European standards and of geologists.

The highly emergent condition of North America at the close of the Paleozoic continued into the Mesozoic, and endured for a long time. The earliest and best marine records of the Triassic and Jurassic occur solely along the Pacific, but late in the latter period much of eastern Mexico sank beneath the Gulf. For these reasons, it appears that the chronology is here again dependent on that of southern Europe. In a broad way, however, it is seen that the two curves on the chart record decided inundations toward the close of the Triassic and Jurassic. Elsewhere in America there are no marine deposits, and the interval between the Permic and the Comanchic has long been well labeled the Jura-Trias.

The Cretaceous is seen to contain two diastrophic cycles—the Comanchic and the Cretacic periods. Both are recognized by Chamberlin and Salisbury in their "Geology."

Tertiary or Neozoic time also divides into two diastrophic cycles agreeing with the recently proposed terms Eogenic and Neogenic (see De Lapparent's Traité).

At the top of the chart has been placed the new classification, the dividing lines being so drawn that these eras and periods may be easily compared with the older scheme shown at the base of the chart. In conclusion, the results here presented, contrasted with the previous classification, are as follows:

The New Geologic Time Table

Old classification		New classification	
Paleozoic	Cambrian	Georgic Acadic Ozarkic or Cambric	Paleozoic
	Ordovician or Lower Silurian	Canadic Ordovicic Cincinnatic	
	Siluric Devonic	Siluric Devonic	Neopaleozoic
	Mississippian or Sub-Carboniferous	Mississippic Tennesseic	
	Pennsylvanic-Permic	Pennsylvanic-Permic	
Mesozoic	Triassic Jurassic	Triassic-Jurassic	Mesozoic
	Cretaceous	Comanchic Cretacic	
Tertiary or Cenozoic	Eocene Oligocene	Eogenic	Neozoic
	Miocene Pliocene Pleistocene	Neogenic	

NORTH AMERICAN PALEOGEOGRAPHY

BY CHARLES SCHUCHERT 1909

EXPLANATION OF SYMBOLS.

LANDS ARE WHITE. WATER AREAS ARE LINED.
FORMATION OUTCROPS SOLID BLACK OR DOTTED.
KNOWN SHORE-LINES ARE SOLID LINES; PROBABLE ONES BROKEN

▨ PACIFIC MARINE

▧ ATLANTIC MARINE

▥ GULF MARINE

▤ ARCTIC MARINE

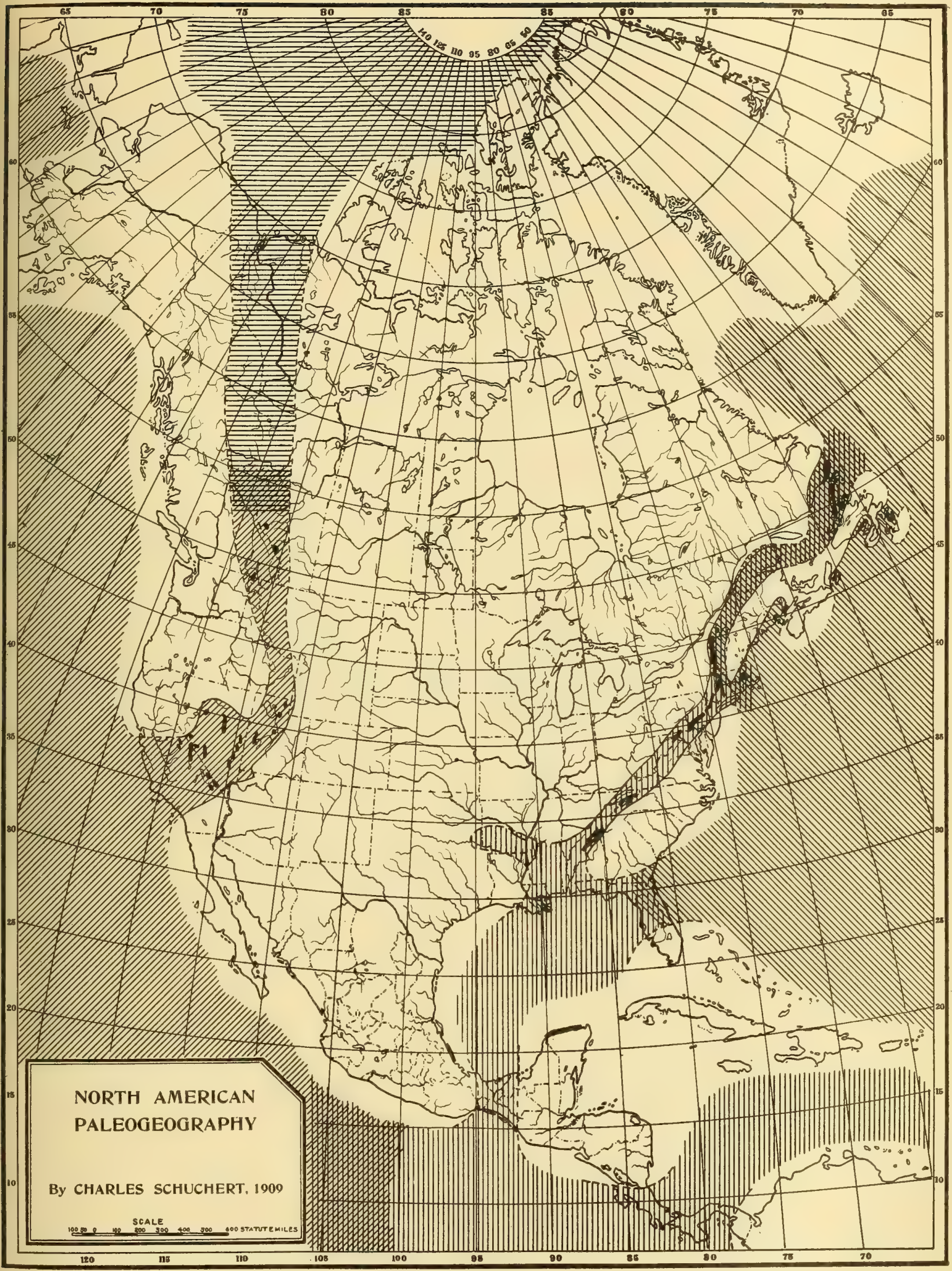
▩ MARINE GYPSUM, OR SALT OR BOTH

▤ INTERBEDDED MARINE & CONTINENTAL DEPOSITS

░ CONTINENTAL DEPOSITS

✳ VOLCANIC EXTRUSIVES

EXPLANATION OF SYMBOLS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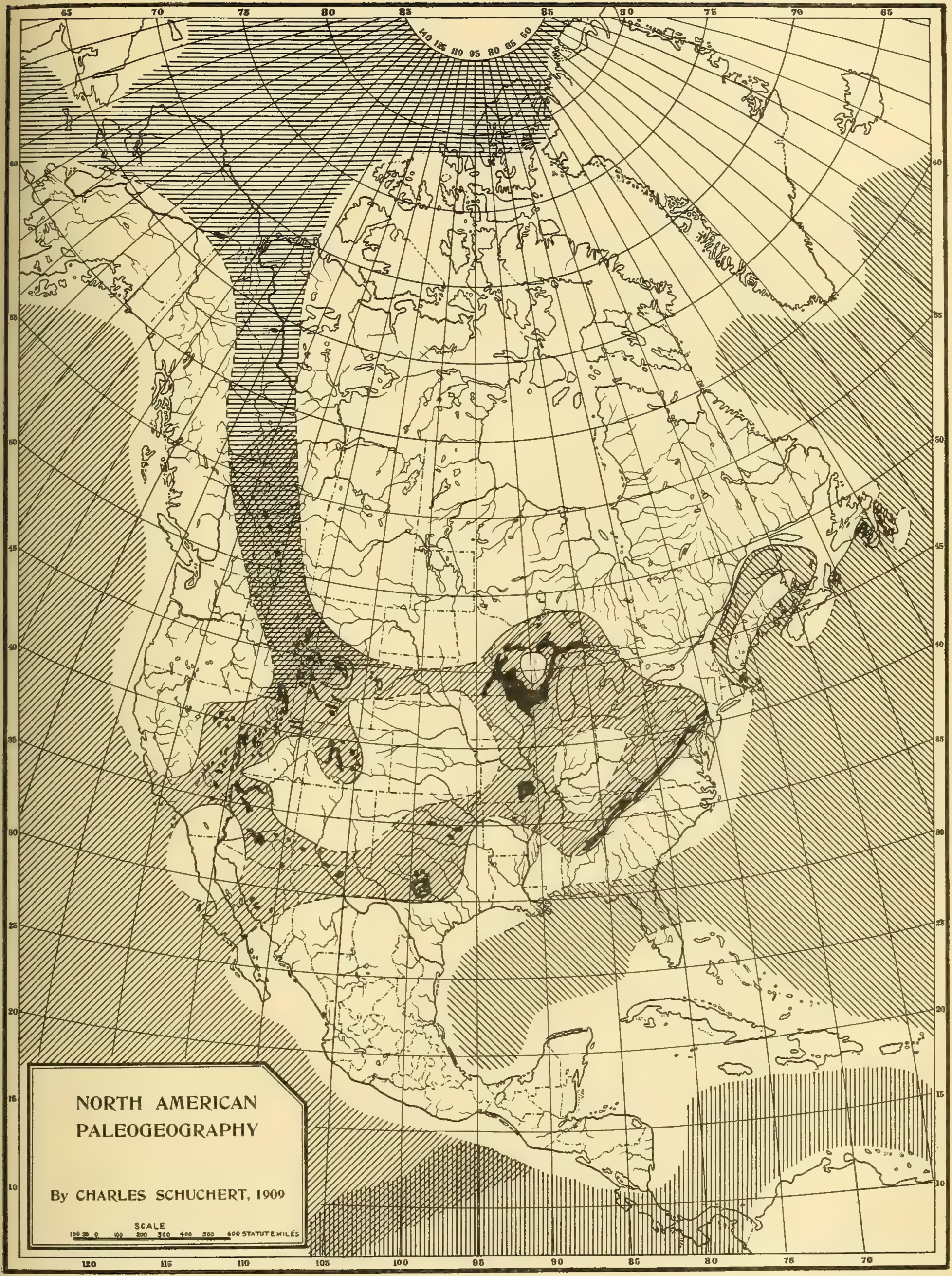
UPPER GEORGIC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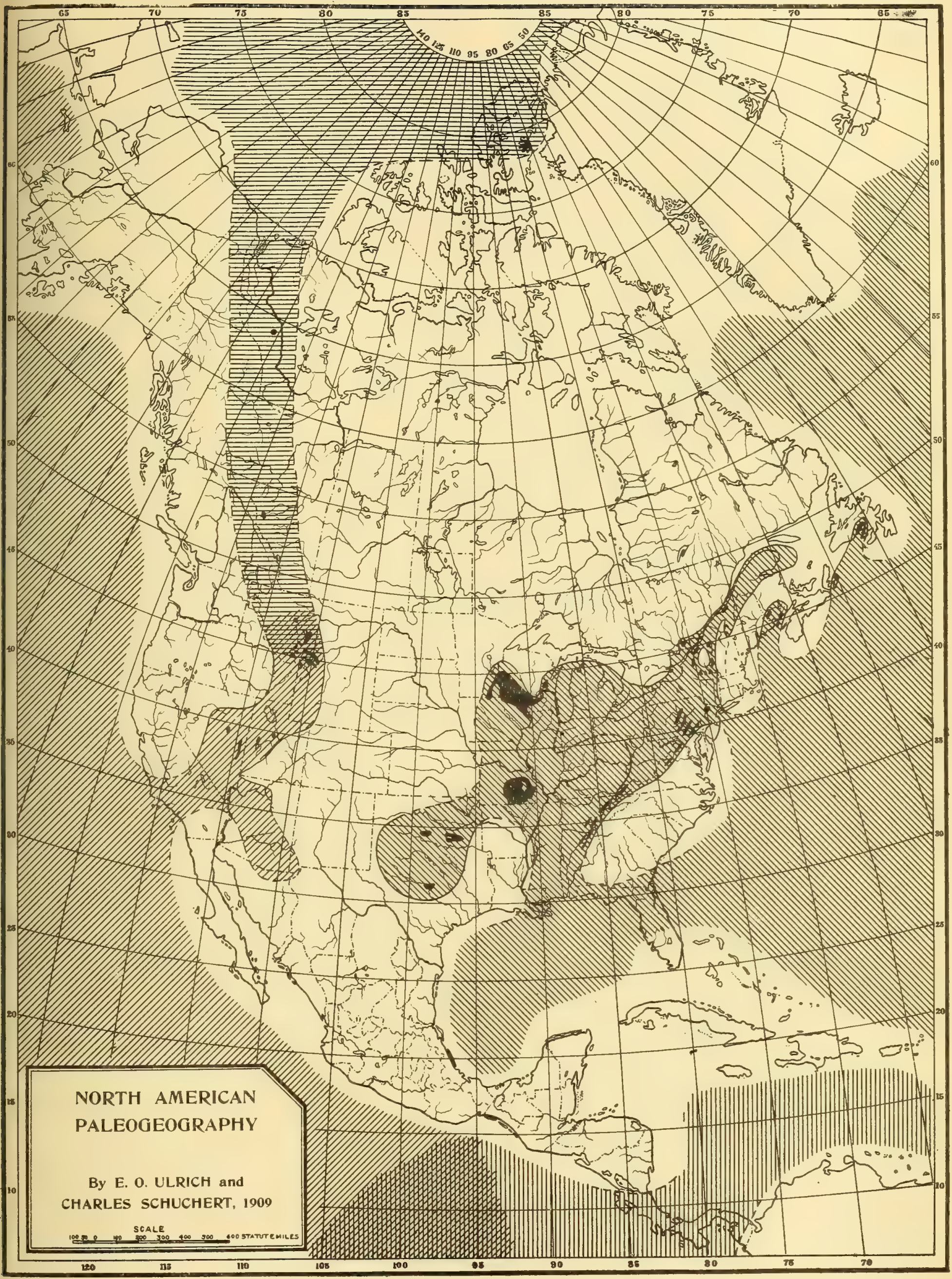
UPPER ACADIC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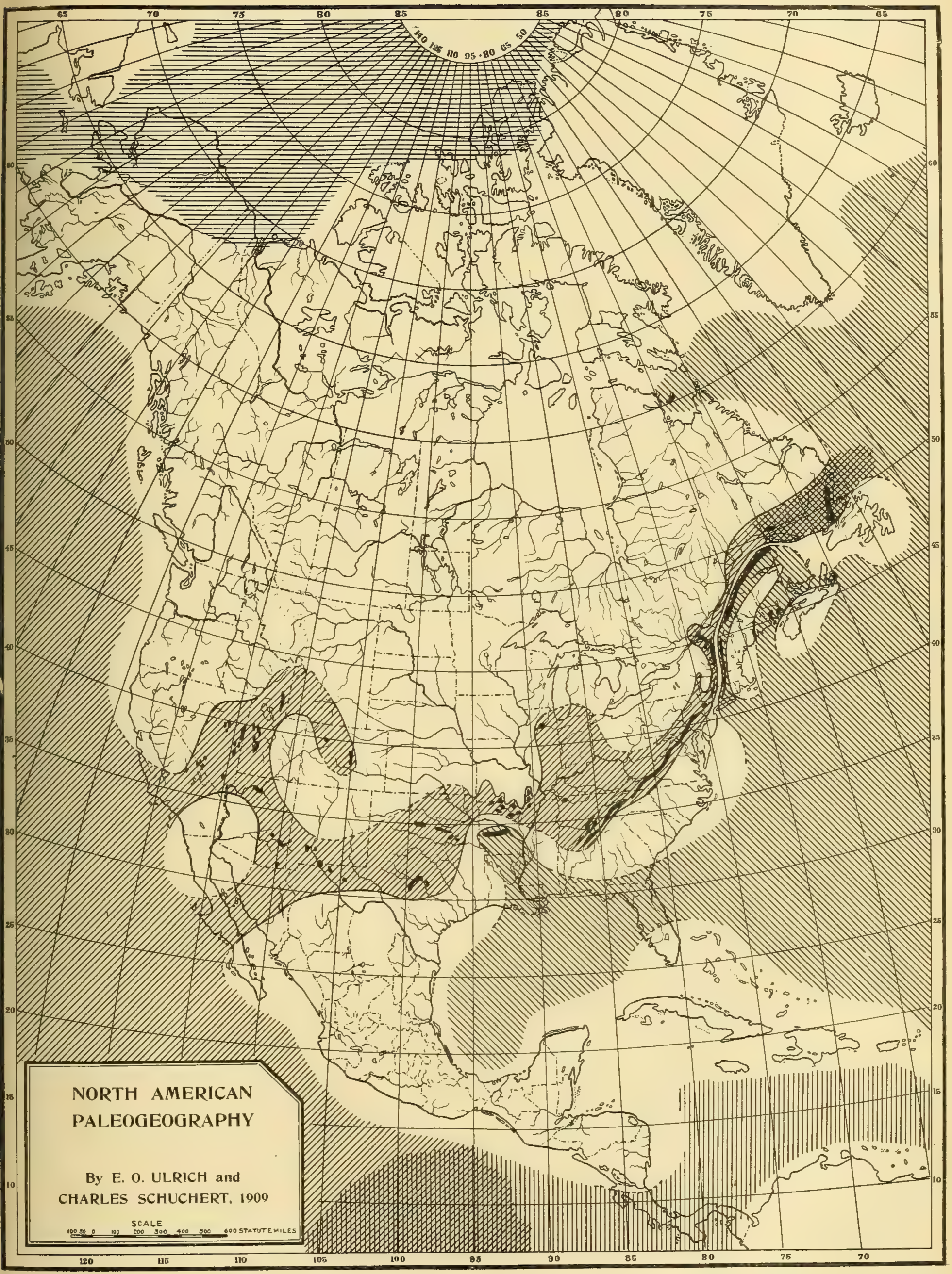
LOWER OZARKIC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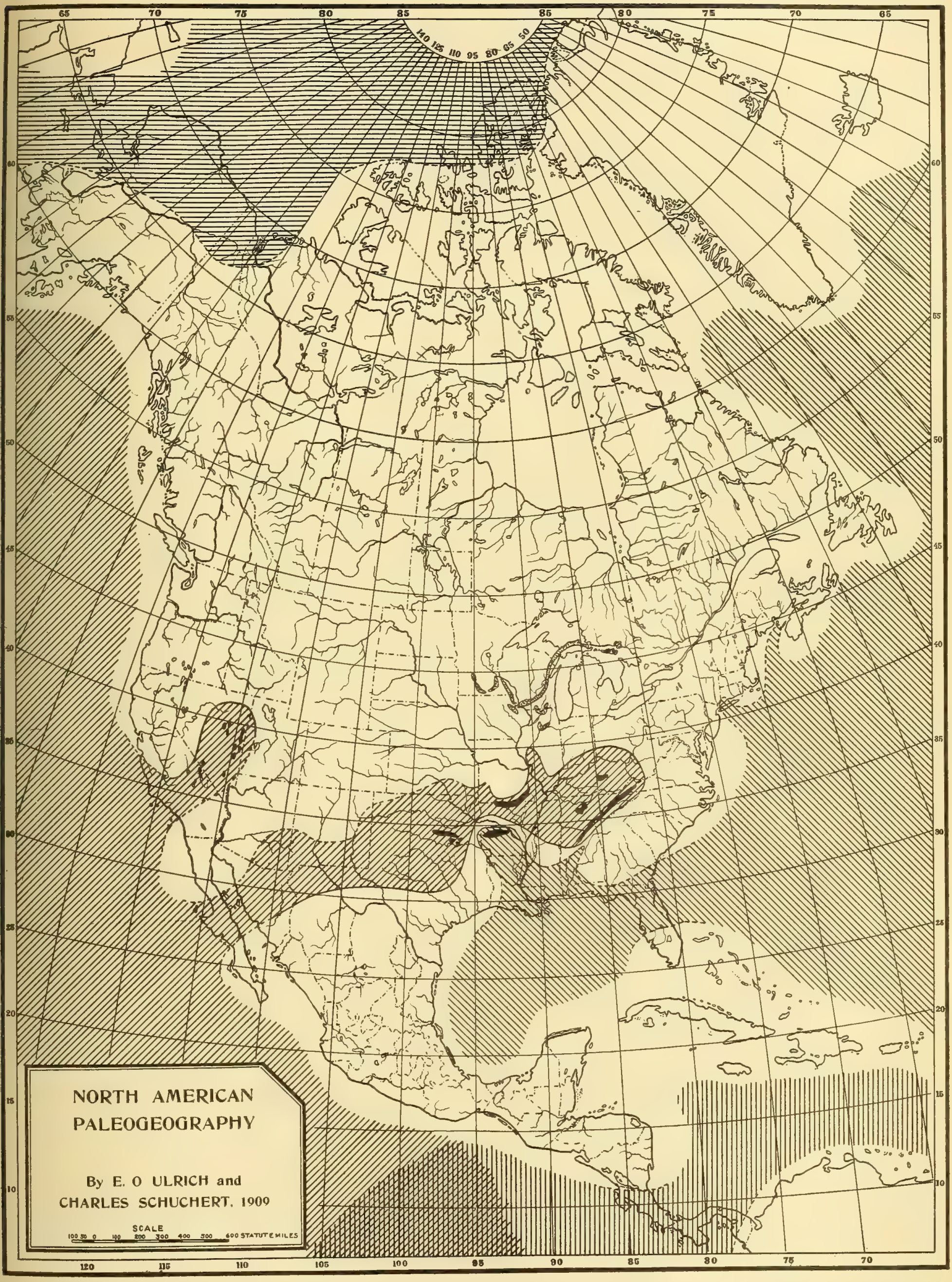
CANADIC (MIDDLE BEEKMANTOWN)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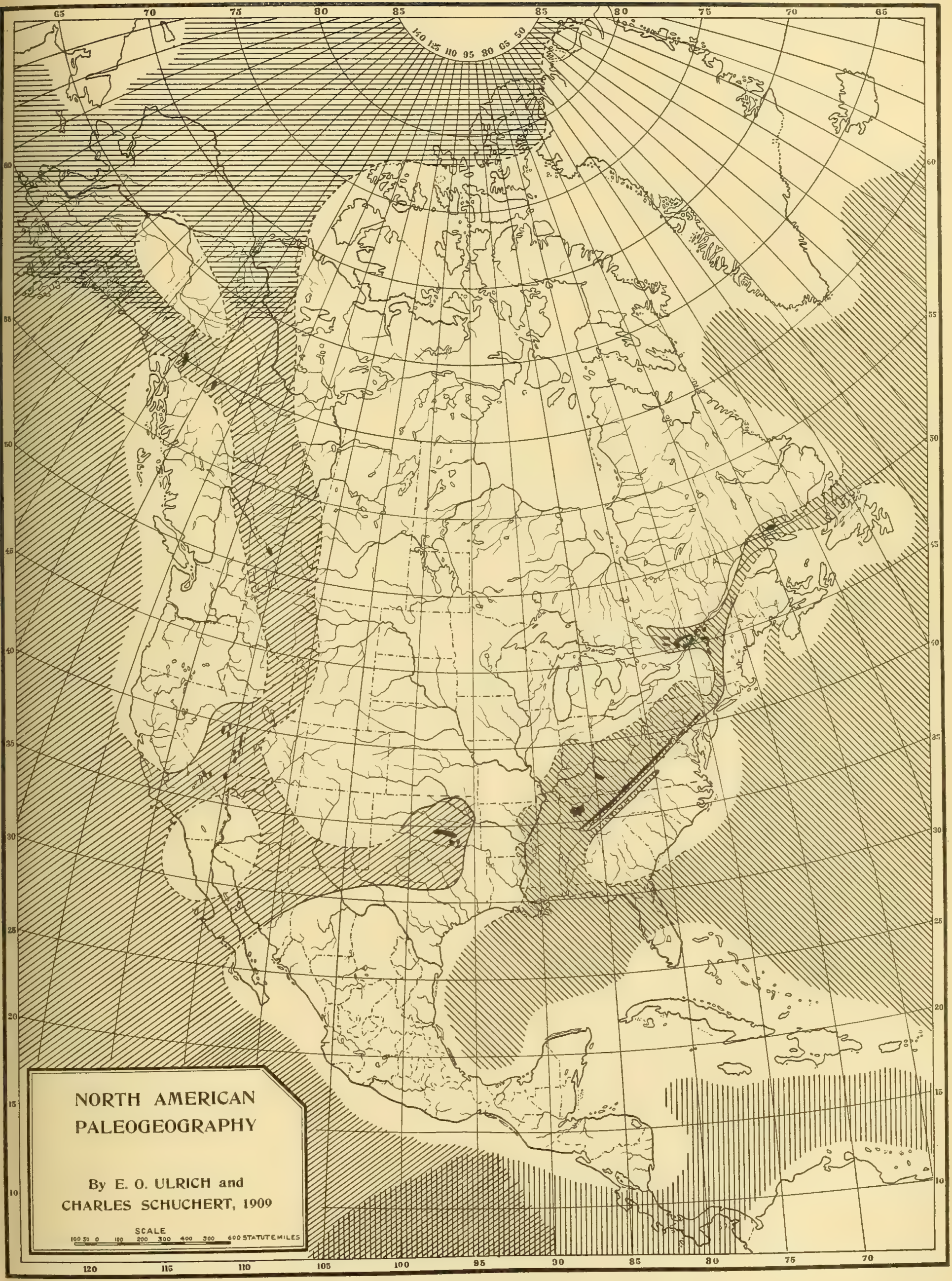
CANADIC (SAINT PETER)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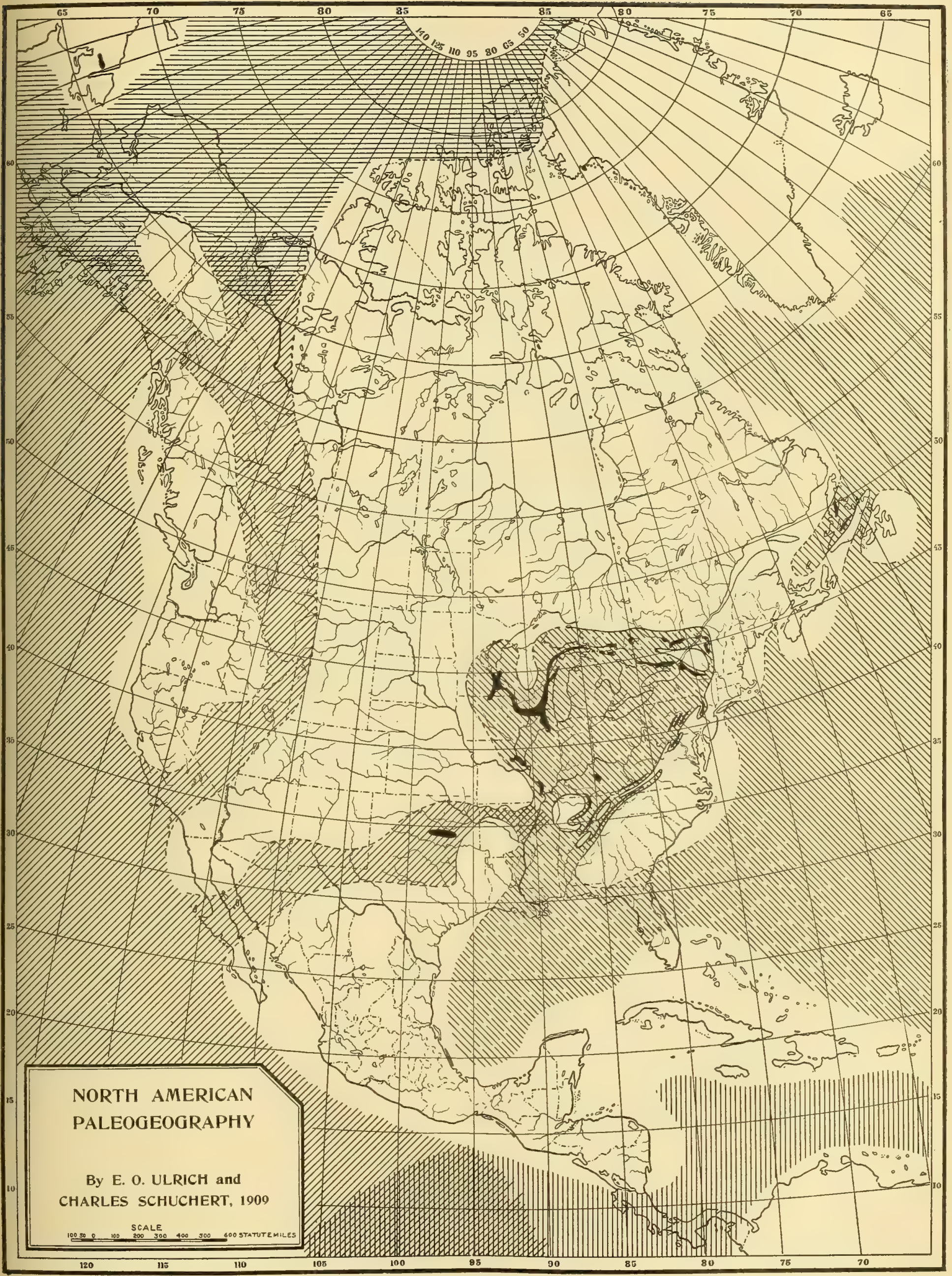
MIDDLE ORDOVICIC (MIDDLE STONES RIVER-CHAZY)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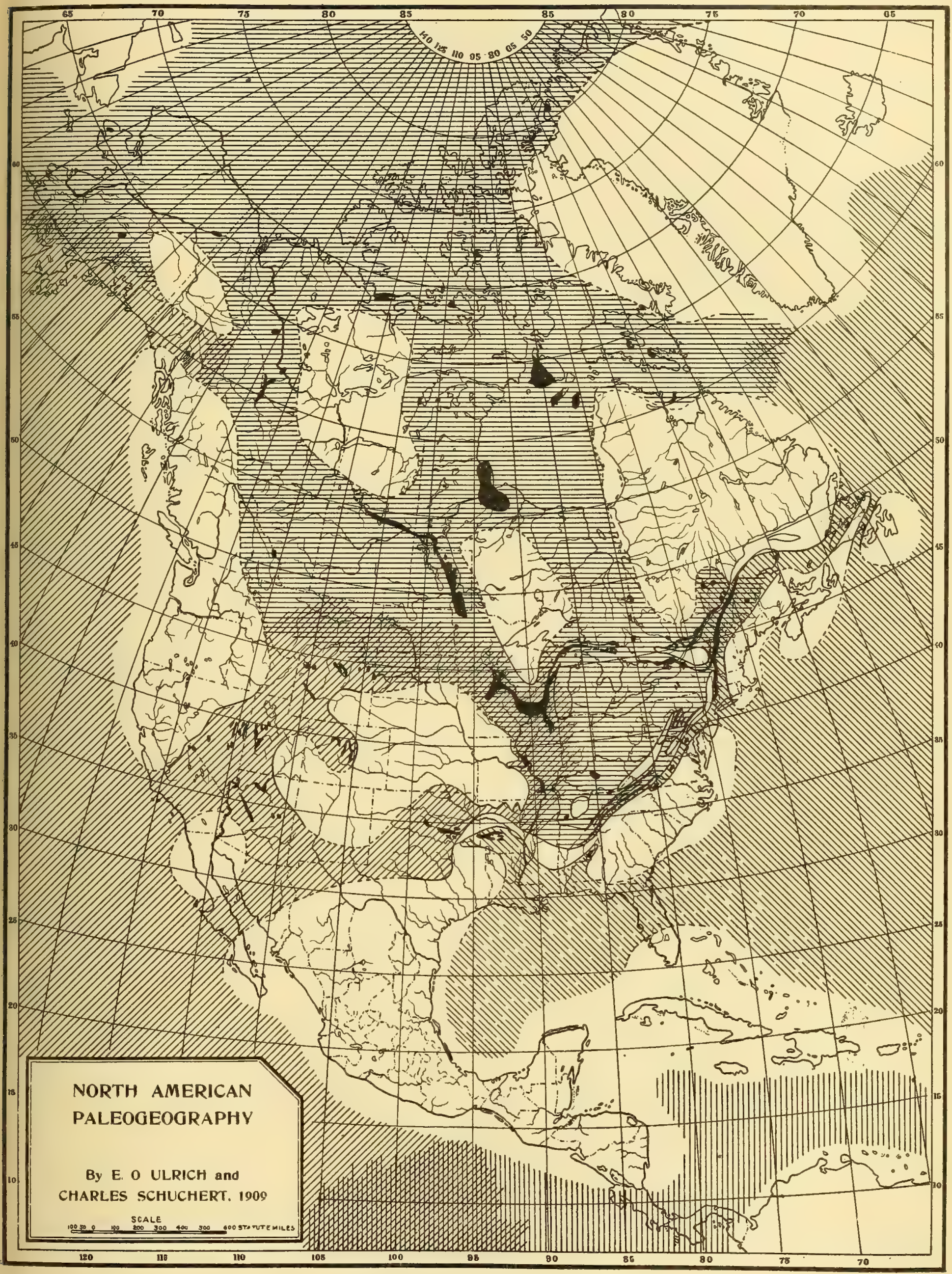

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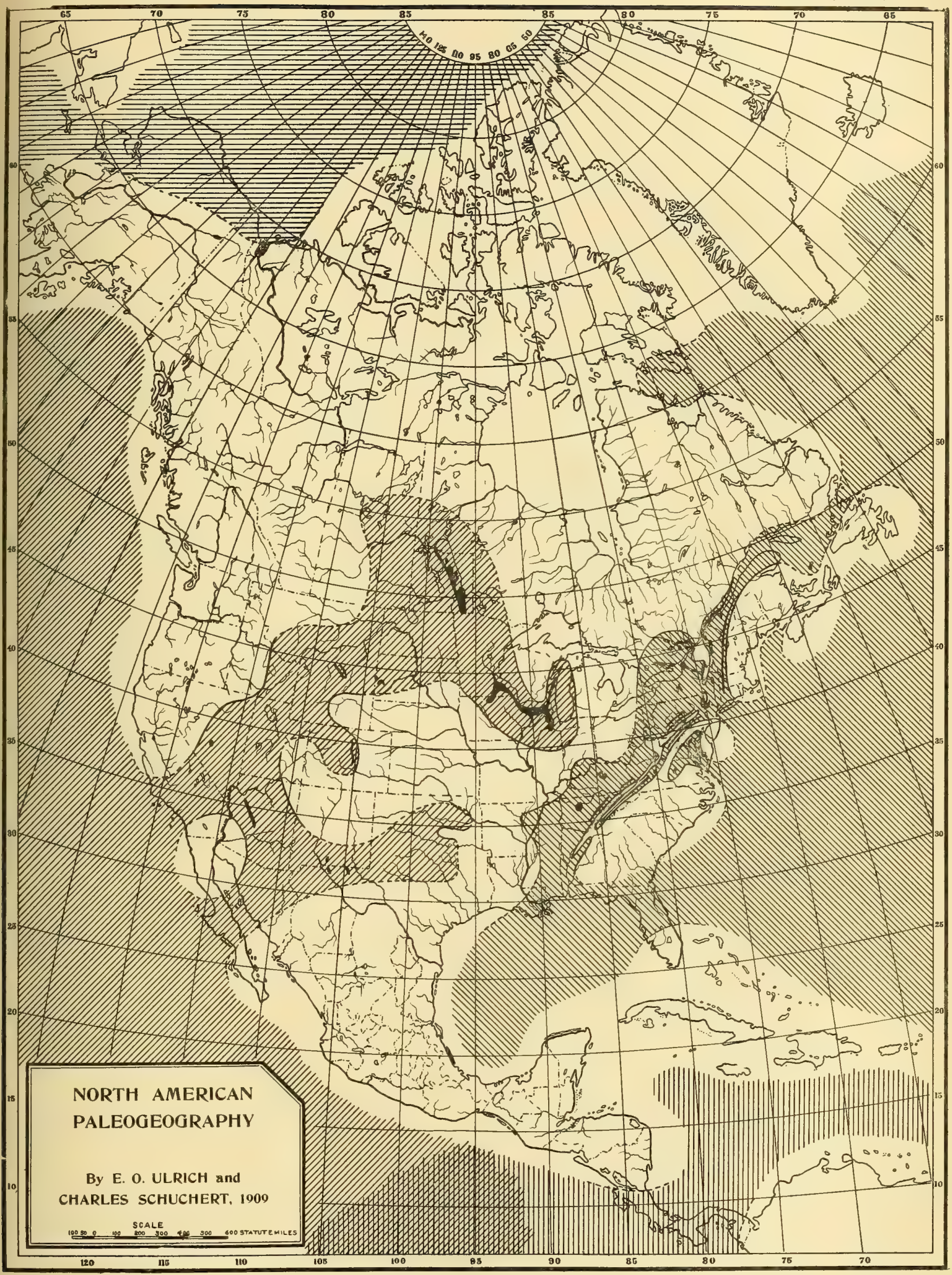
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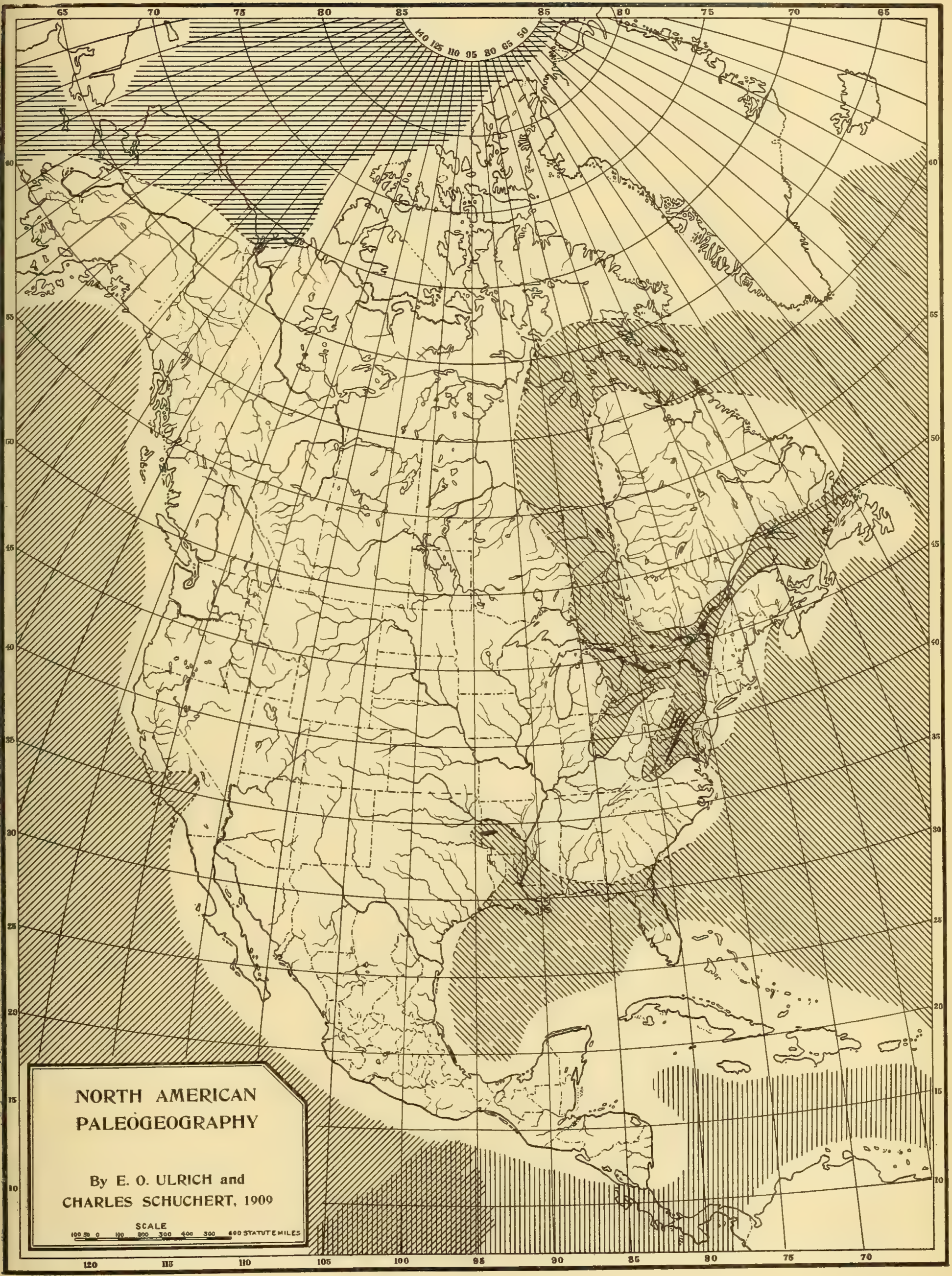
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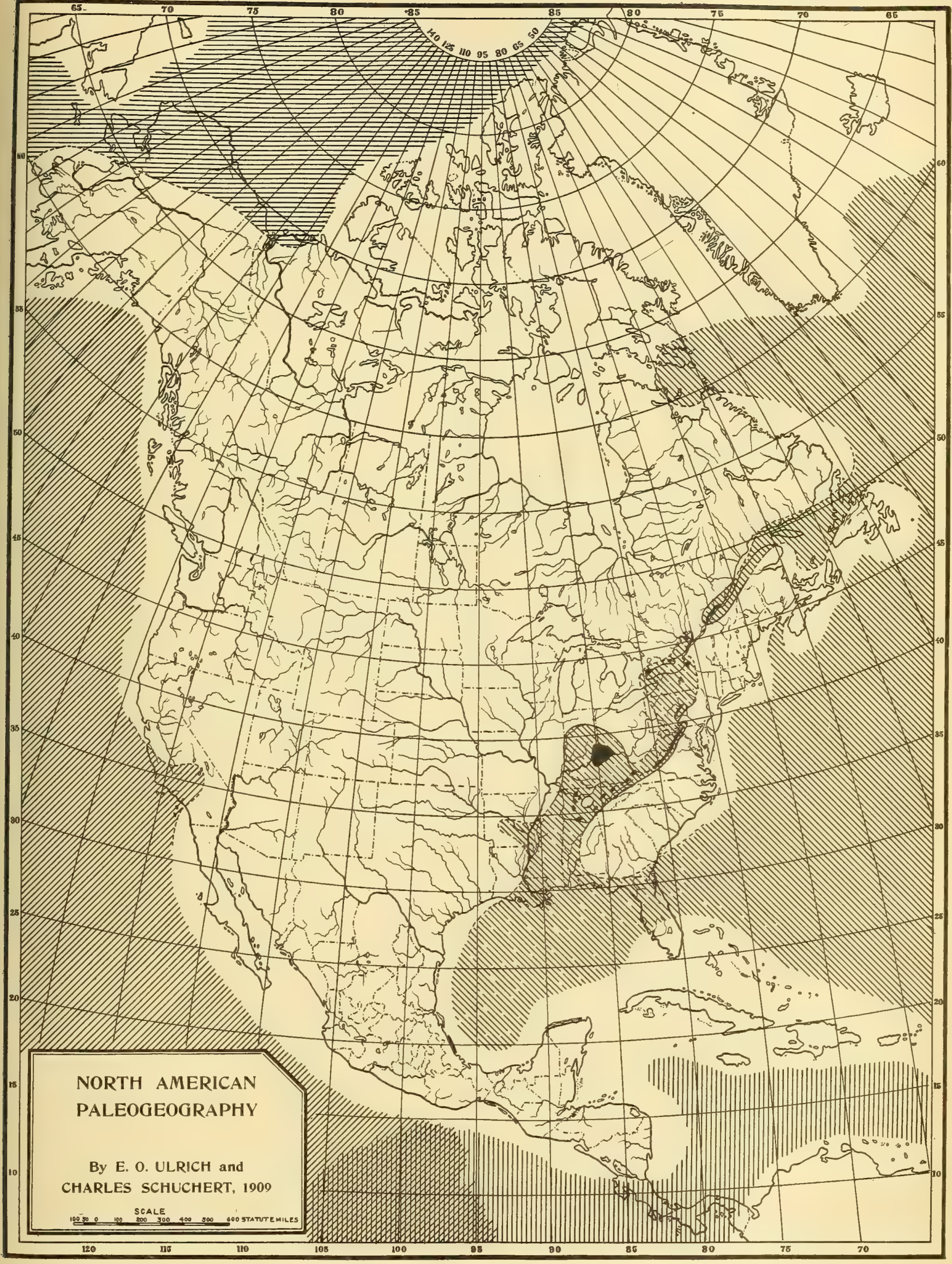
UPPER ORDOVICIC (UTICA)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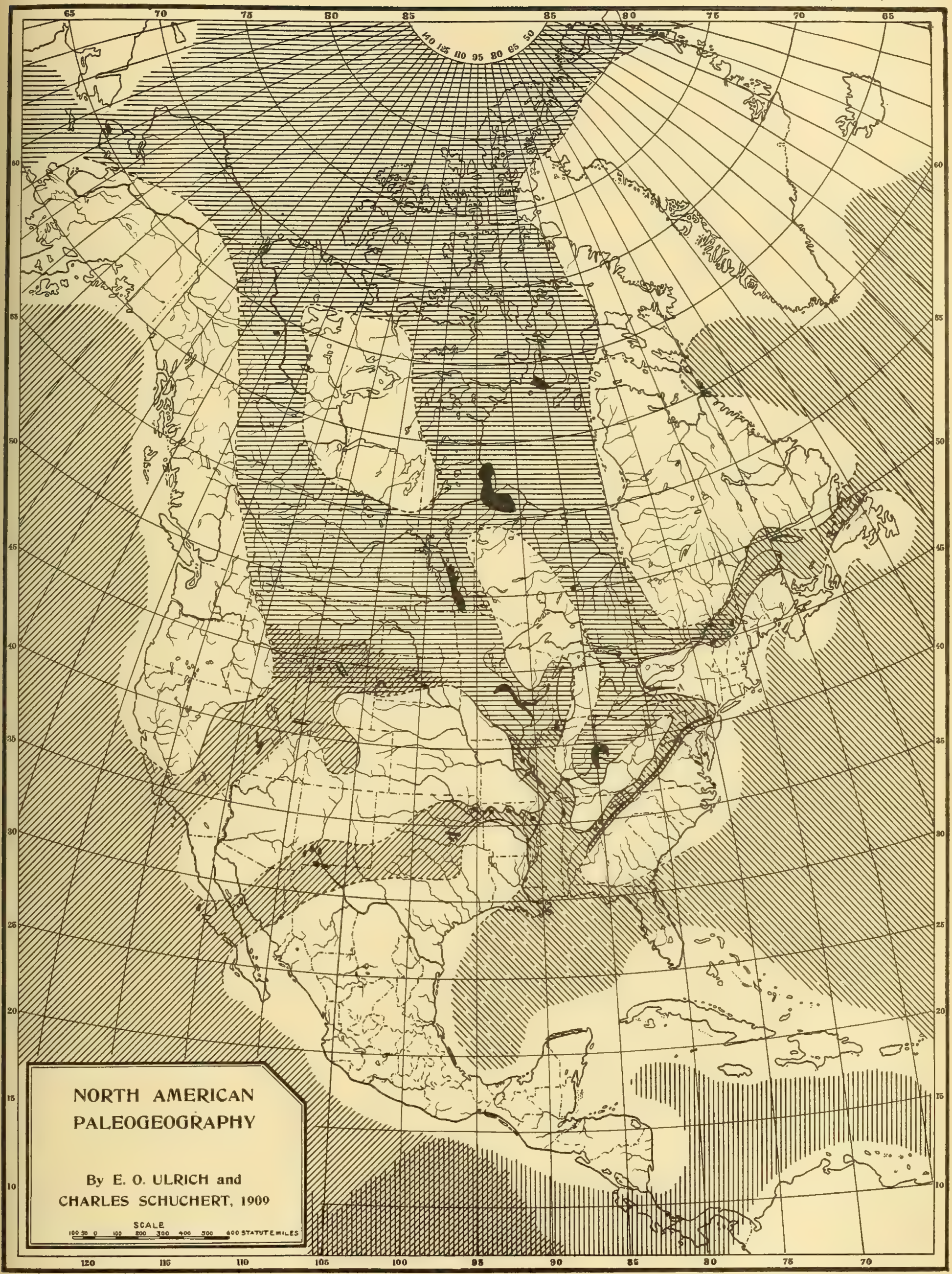
CINCINNATIC (LORRAINE)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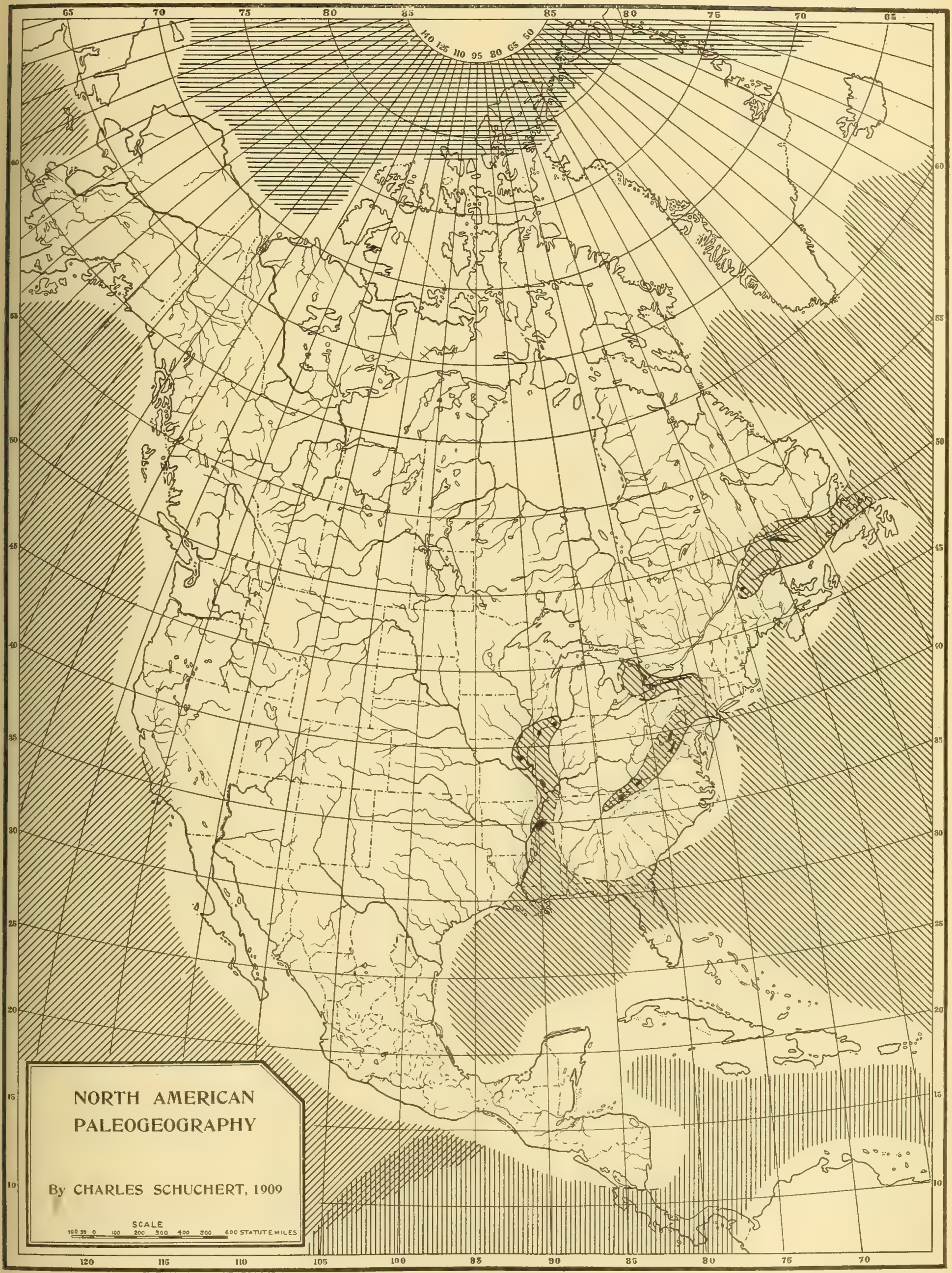
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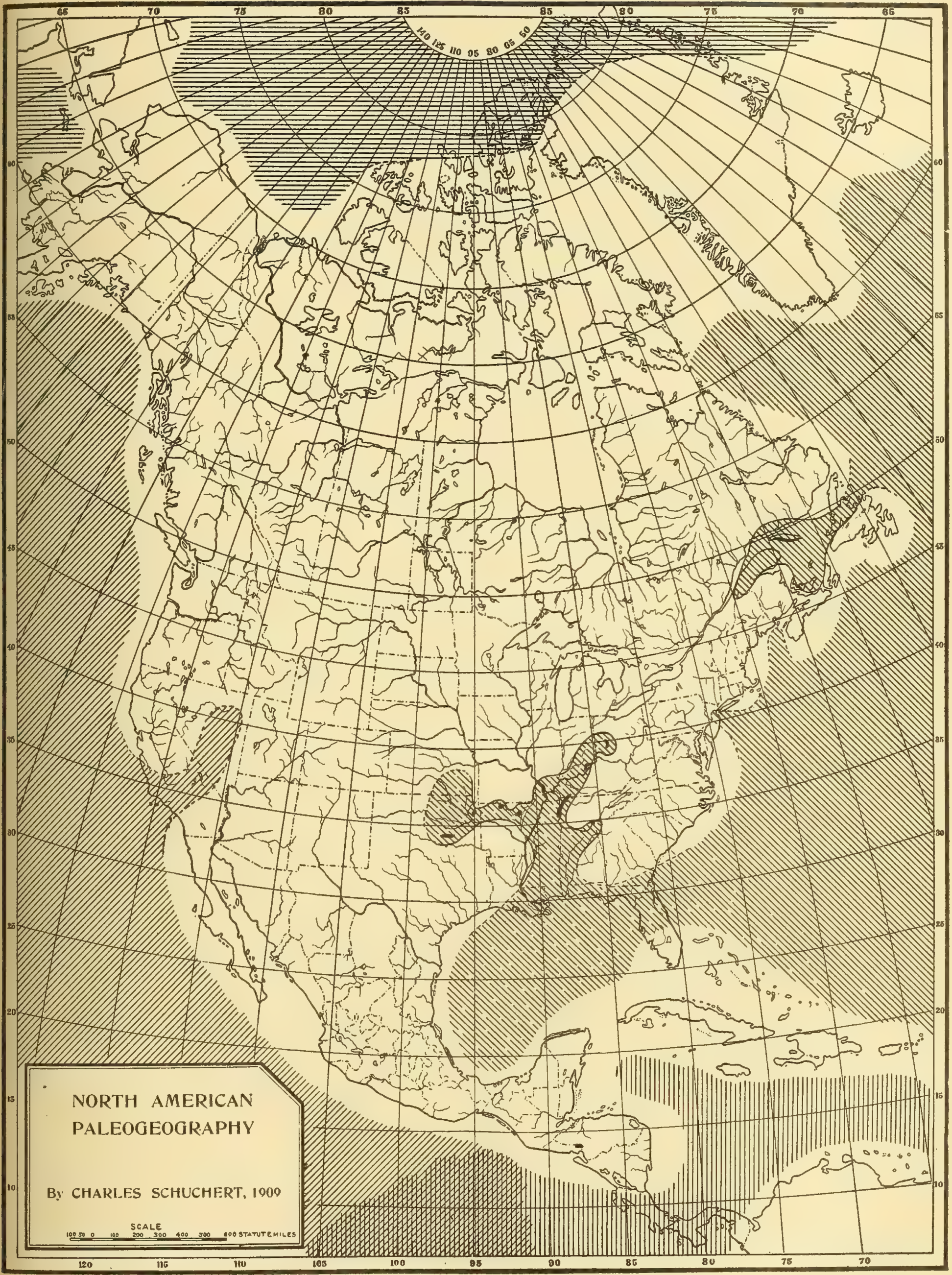
LOWER SILURIC (UPPER MEDINA-EDGEWOOD)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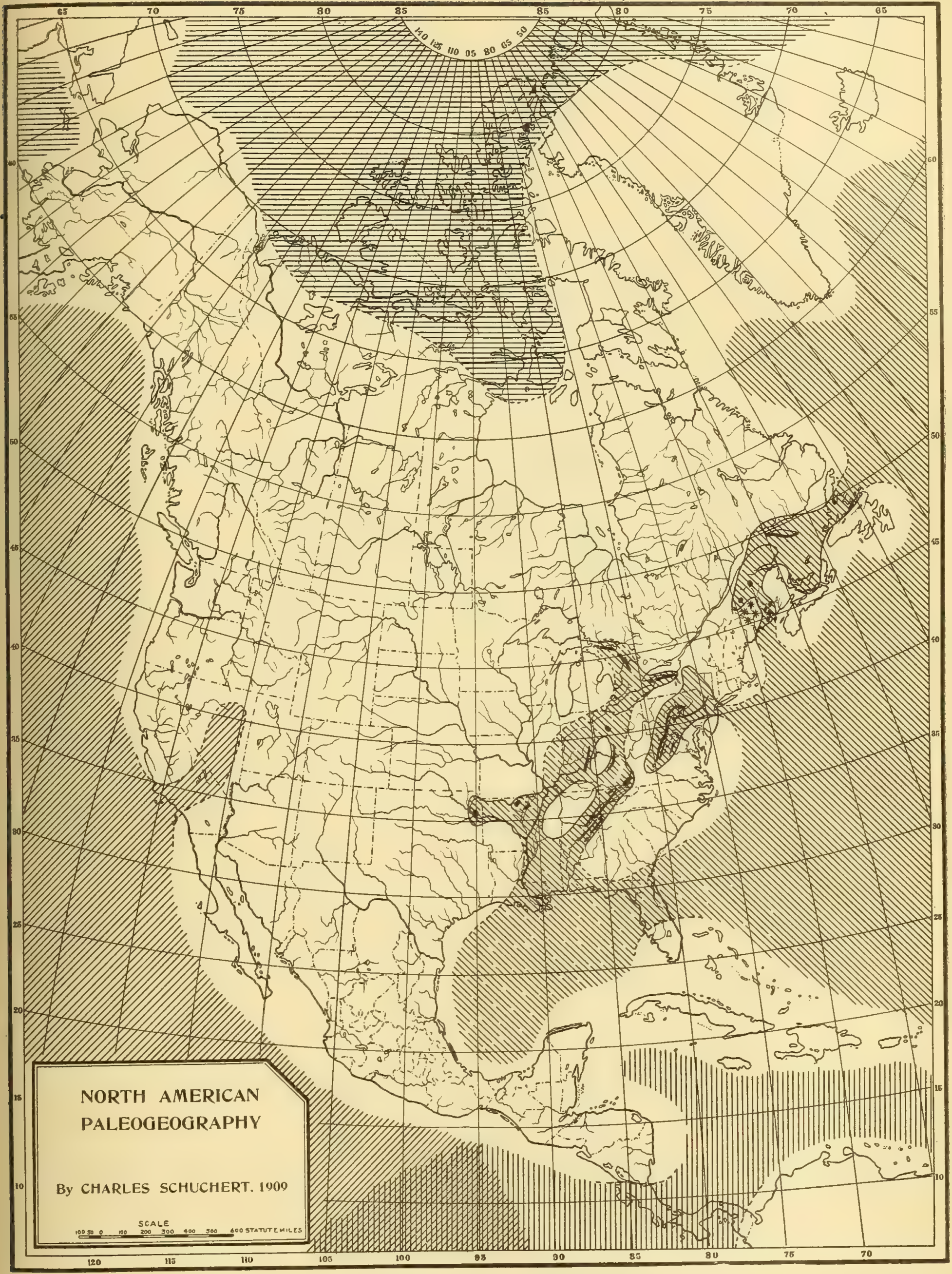
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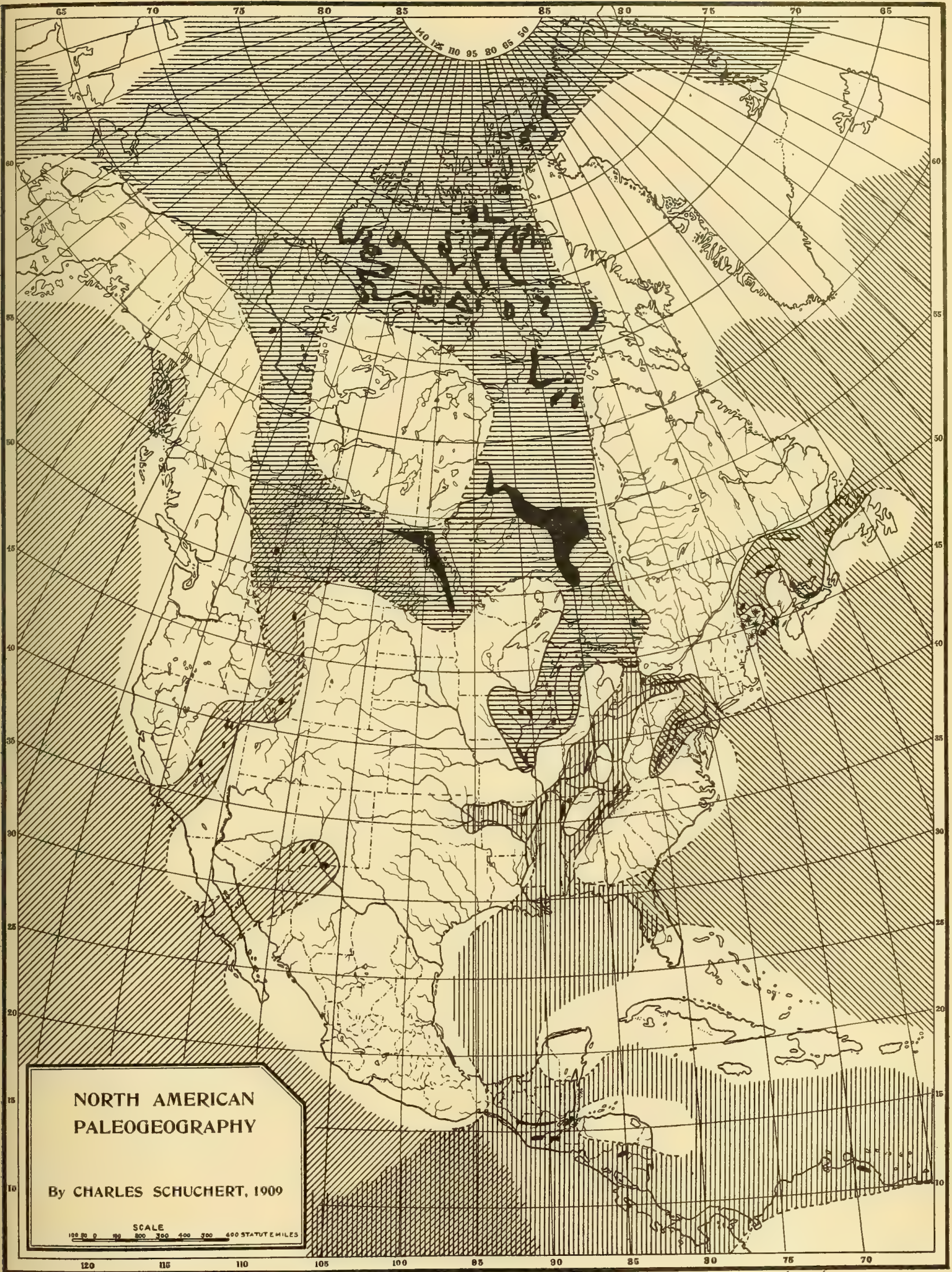
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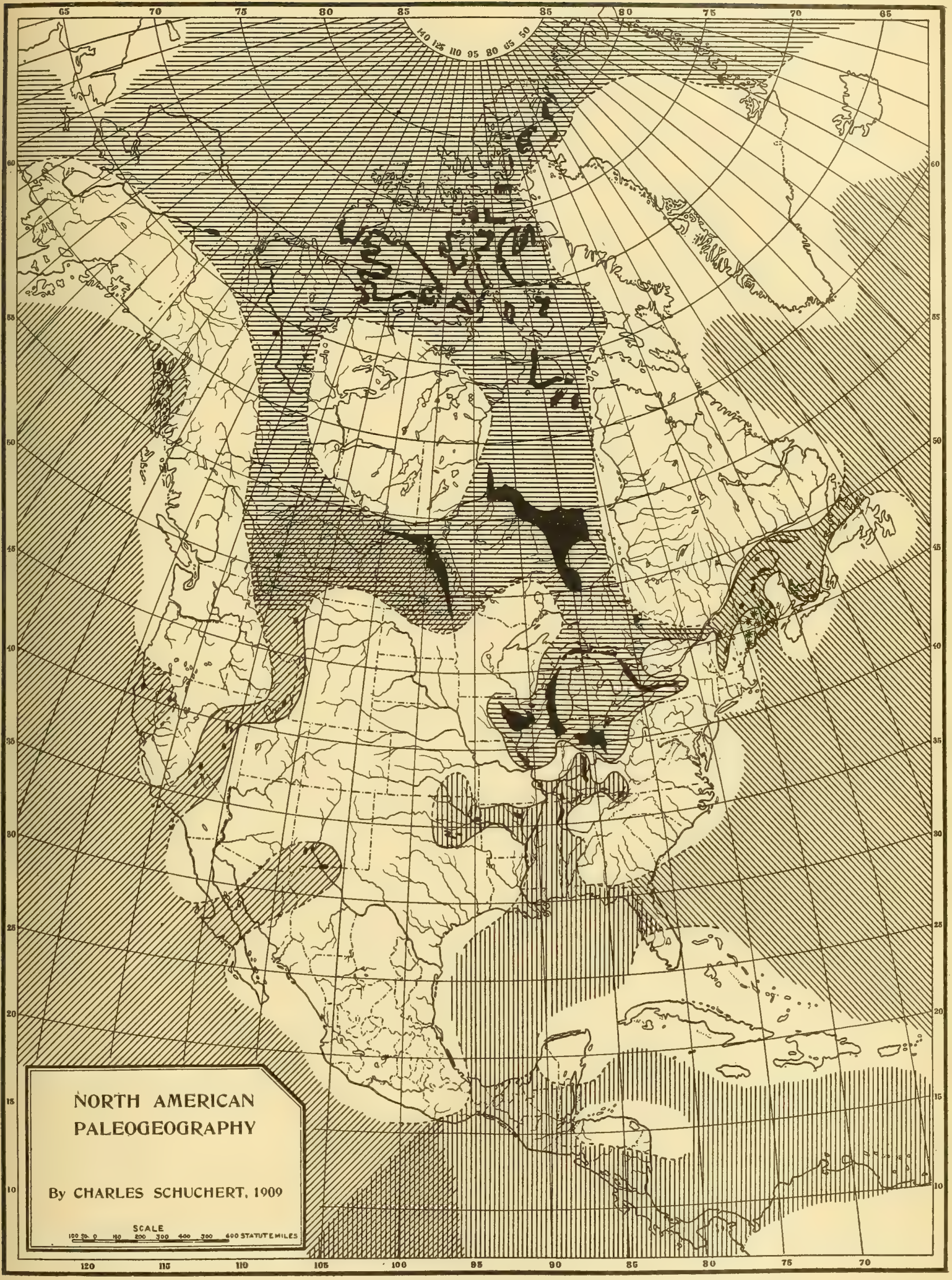
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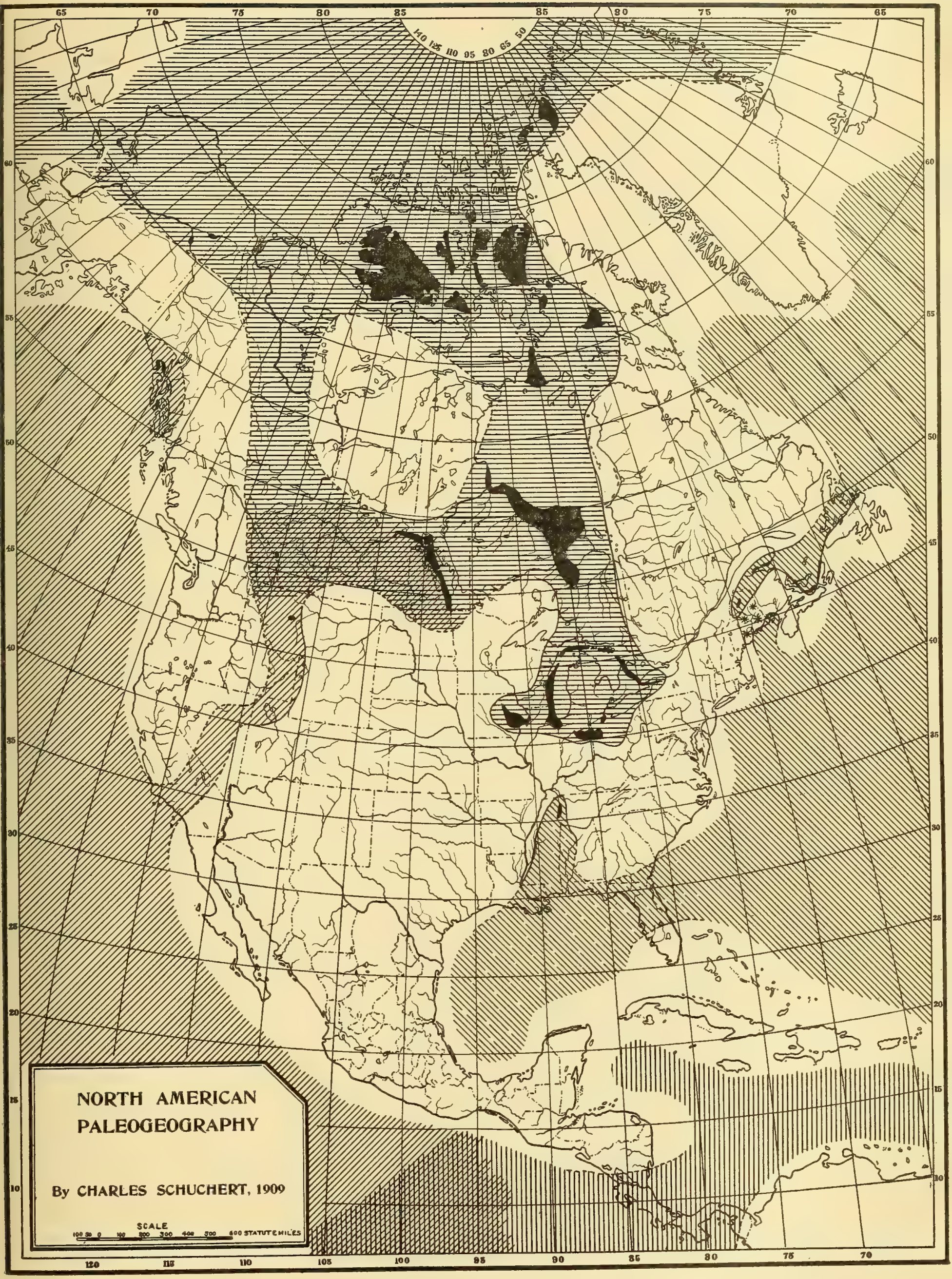
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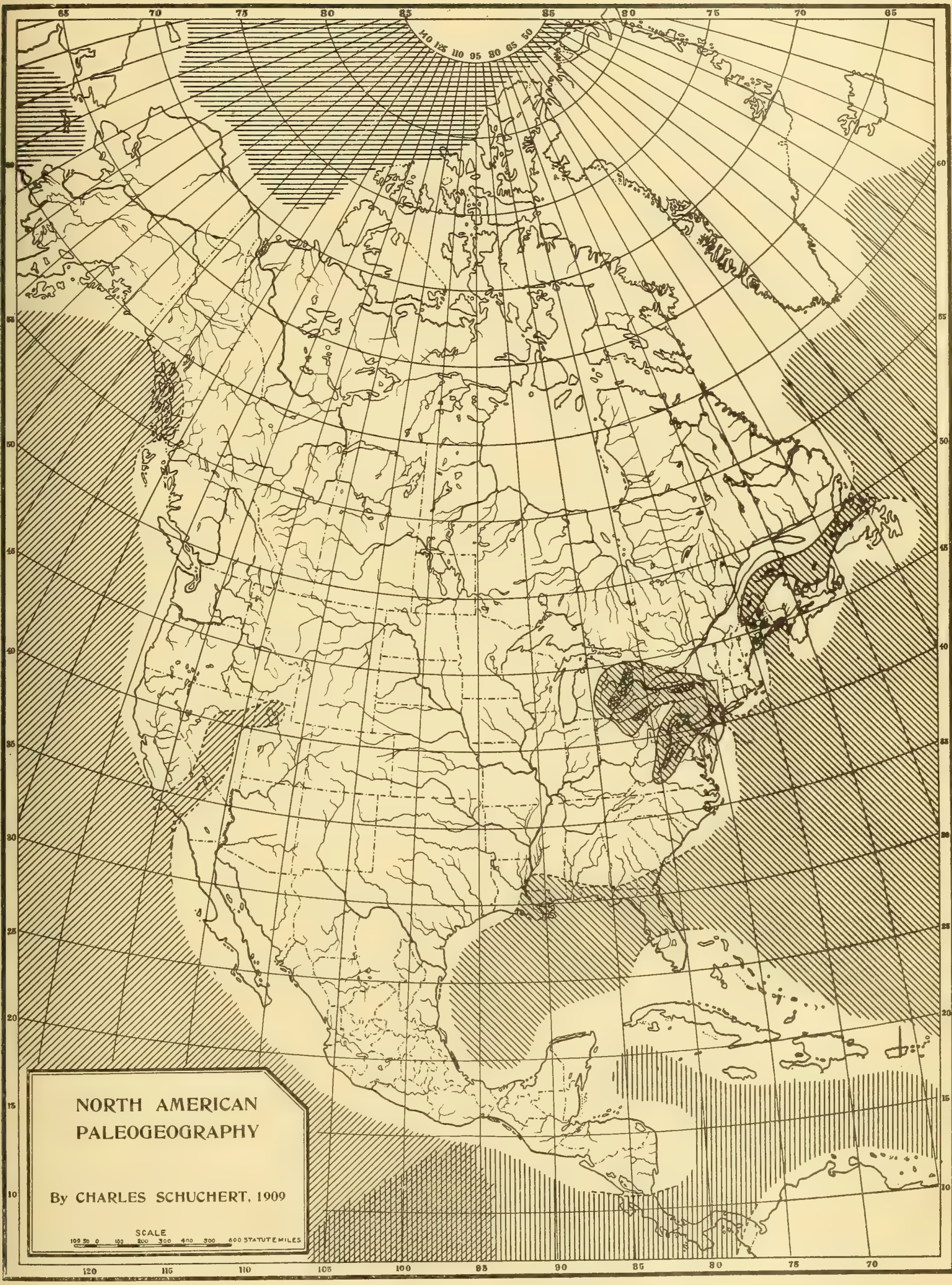
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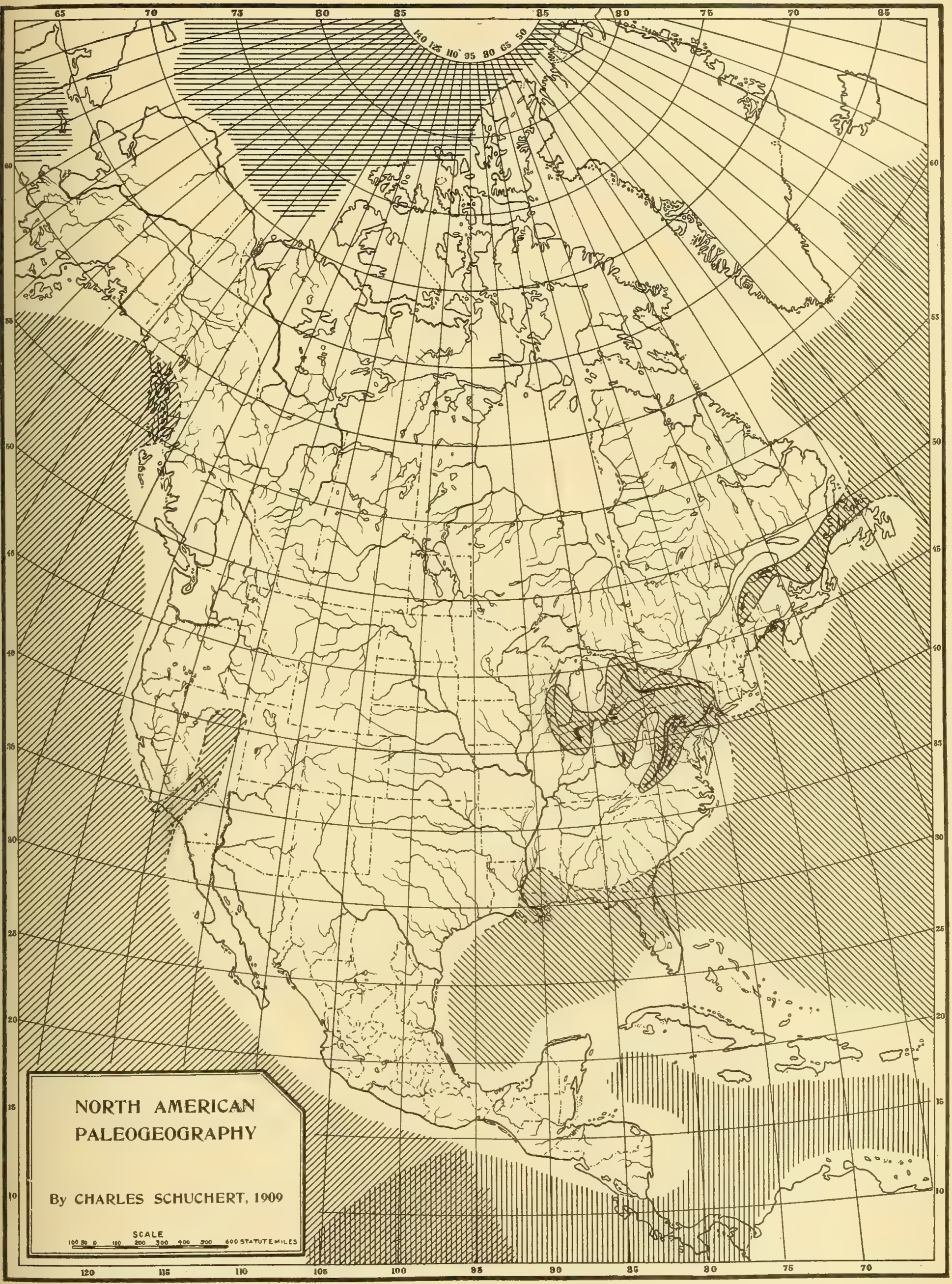
UPPER SILURIC (LOWER SALINA)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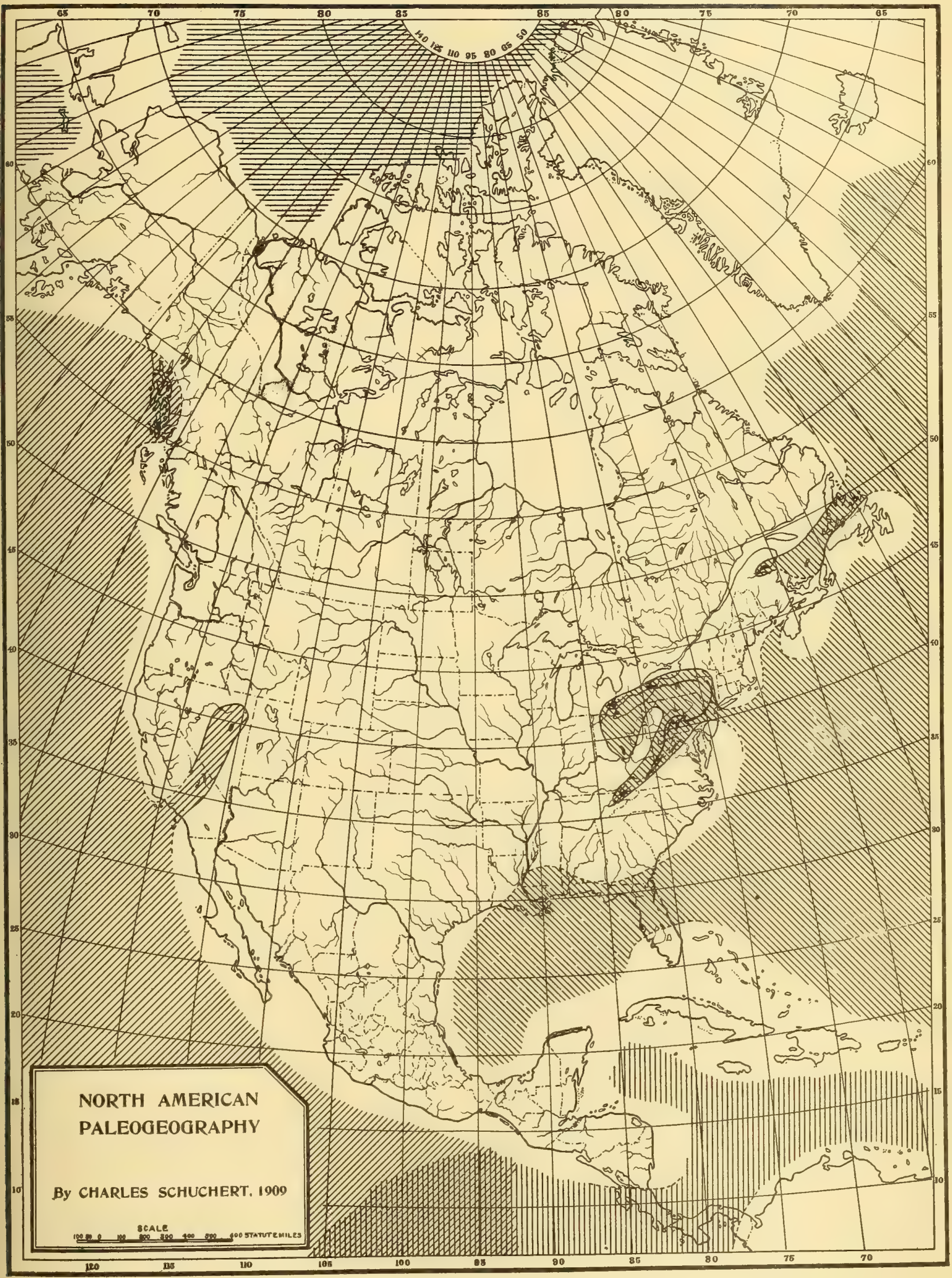
UPPER SILURIC (BERTIE)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SCALE
STATUTE MILES

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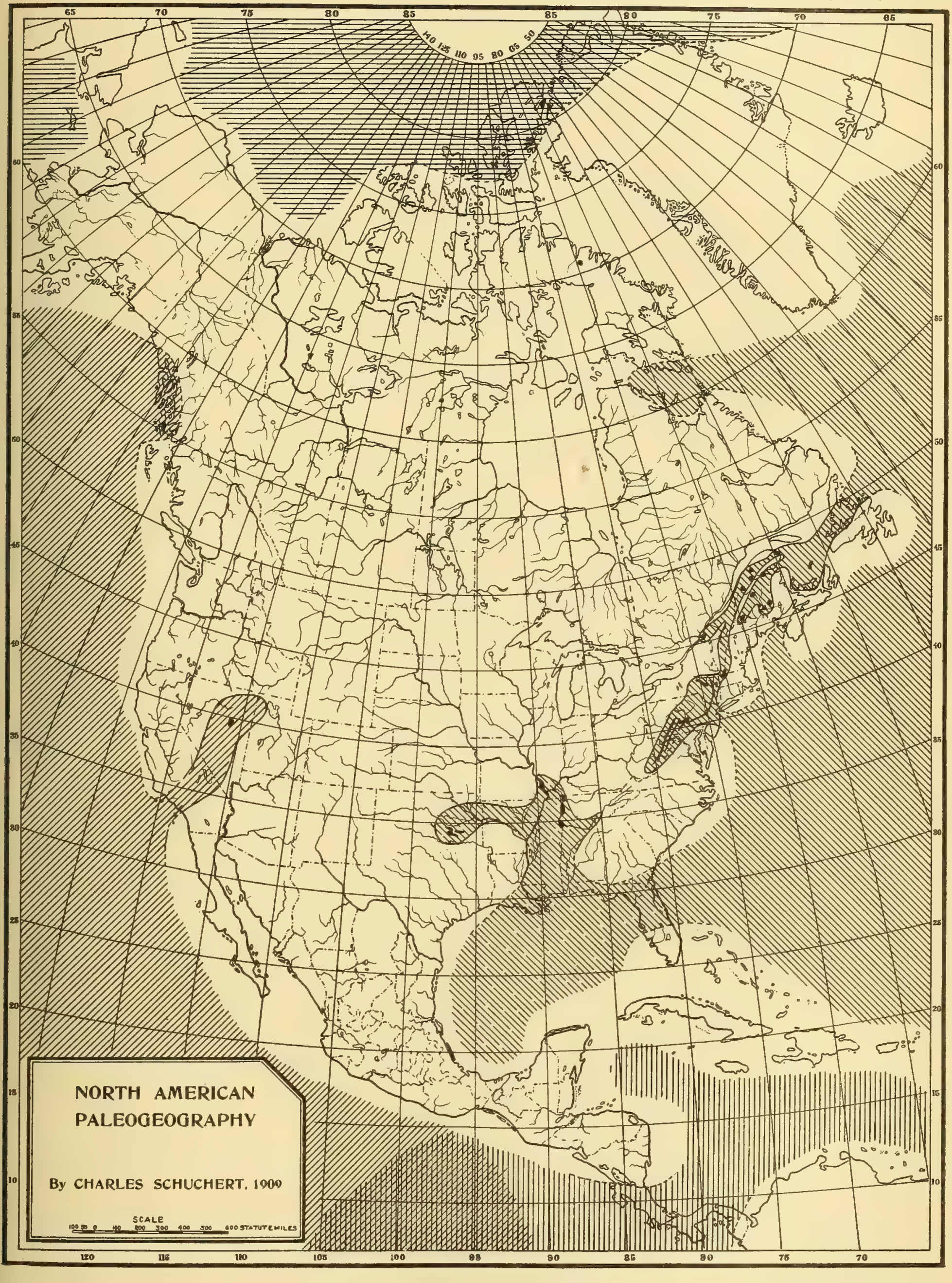
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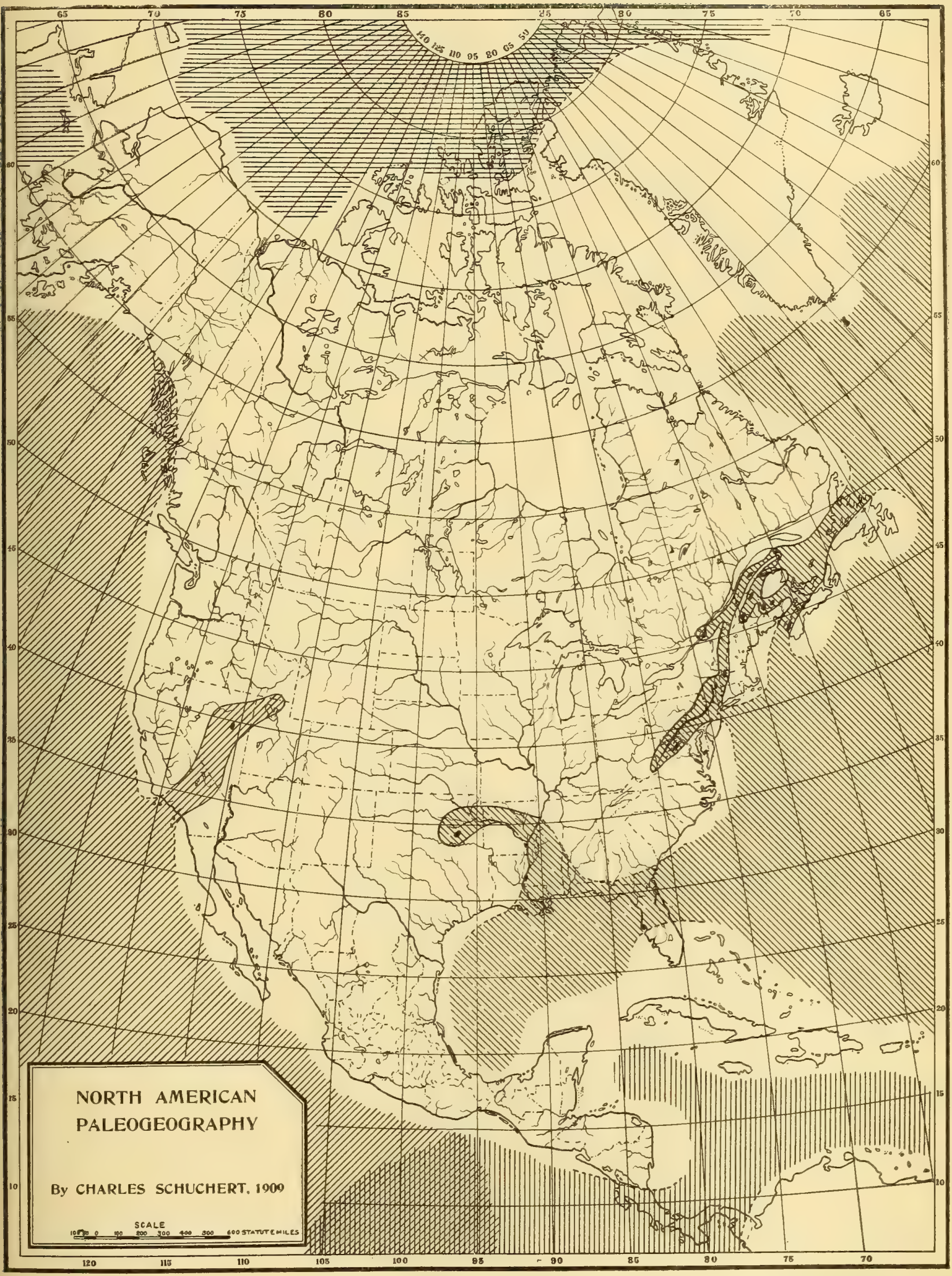
LOWER DEVONIC (NEW SCOTLAND)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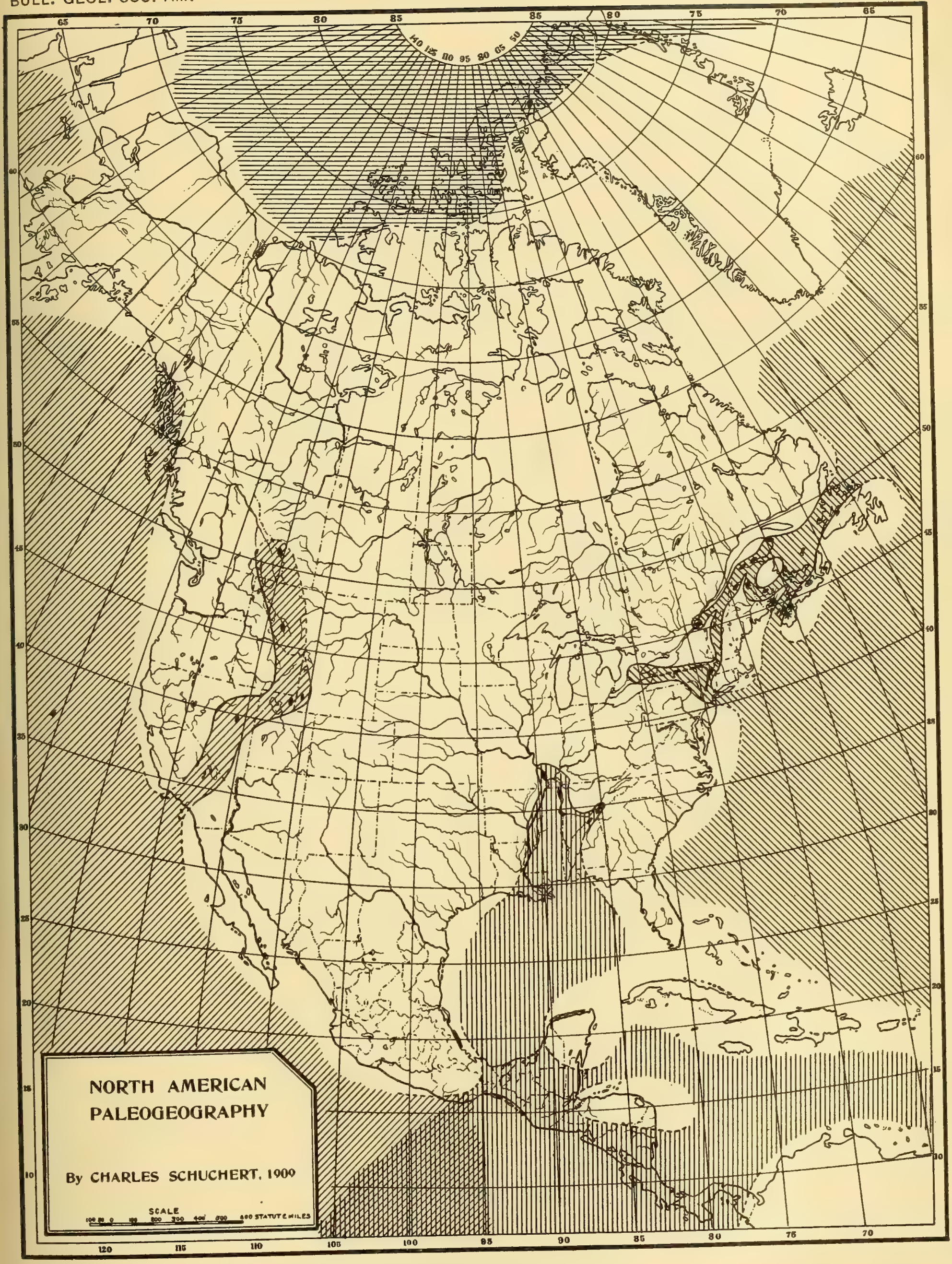
LOWER DEVONIC (BECRAFT)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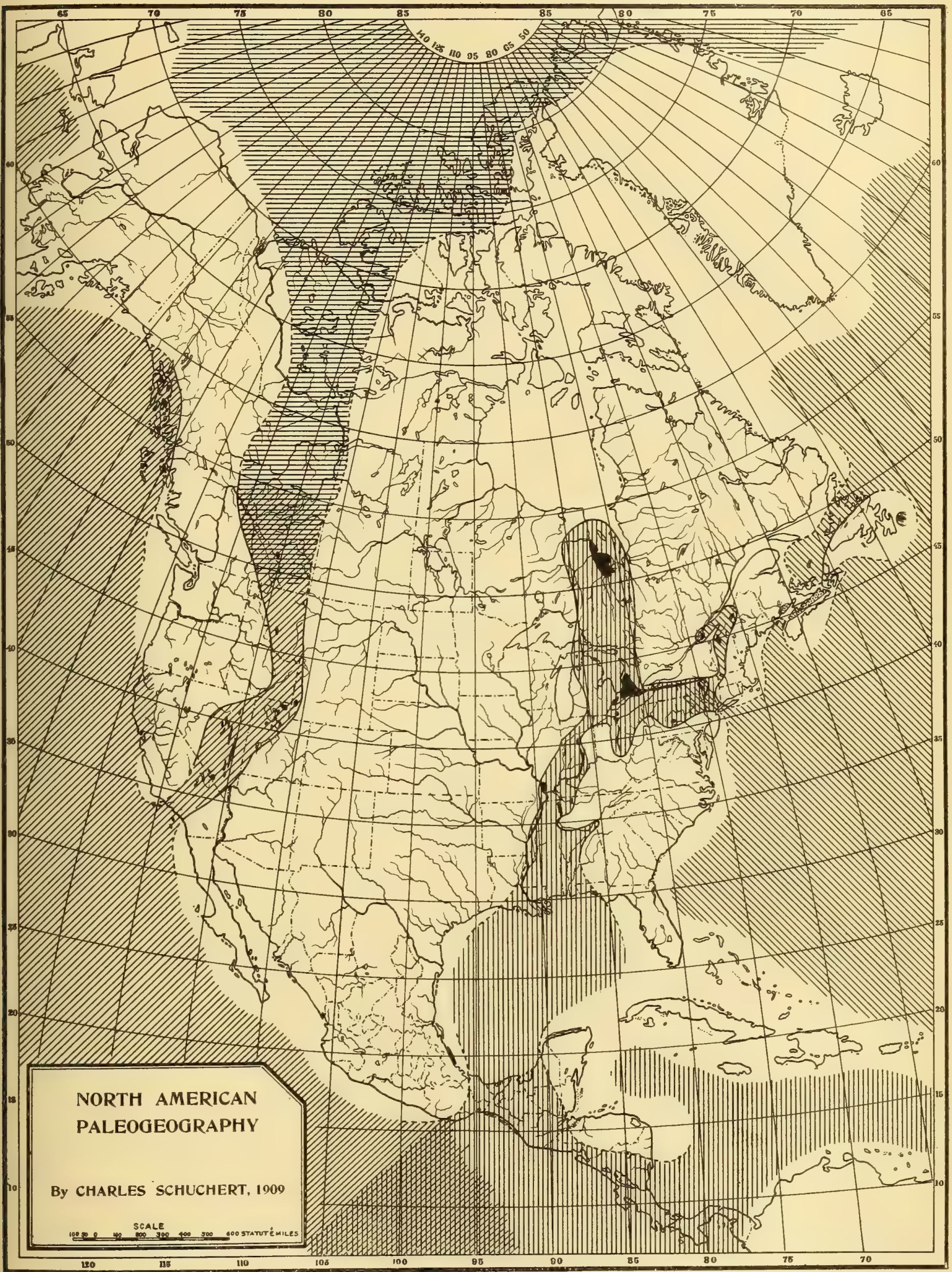
LOWER DEVONIC (DECEWVILLE)



NORTH AMERICAN PALEOGEOGRAPHY
By CHARLES SCHUCHERT, 1909
SCALE
STATUTE MILES

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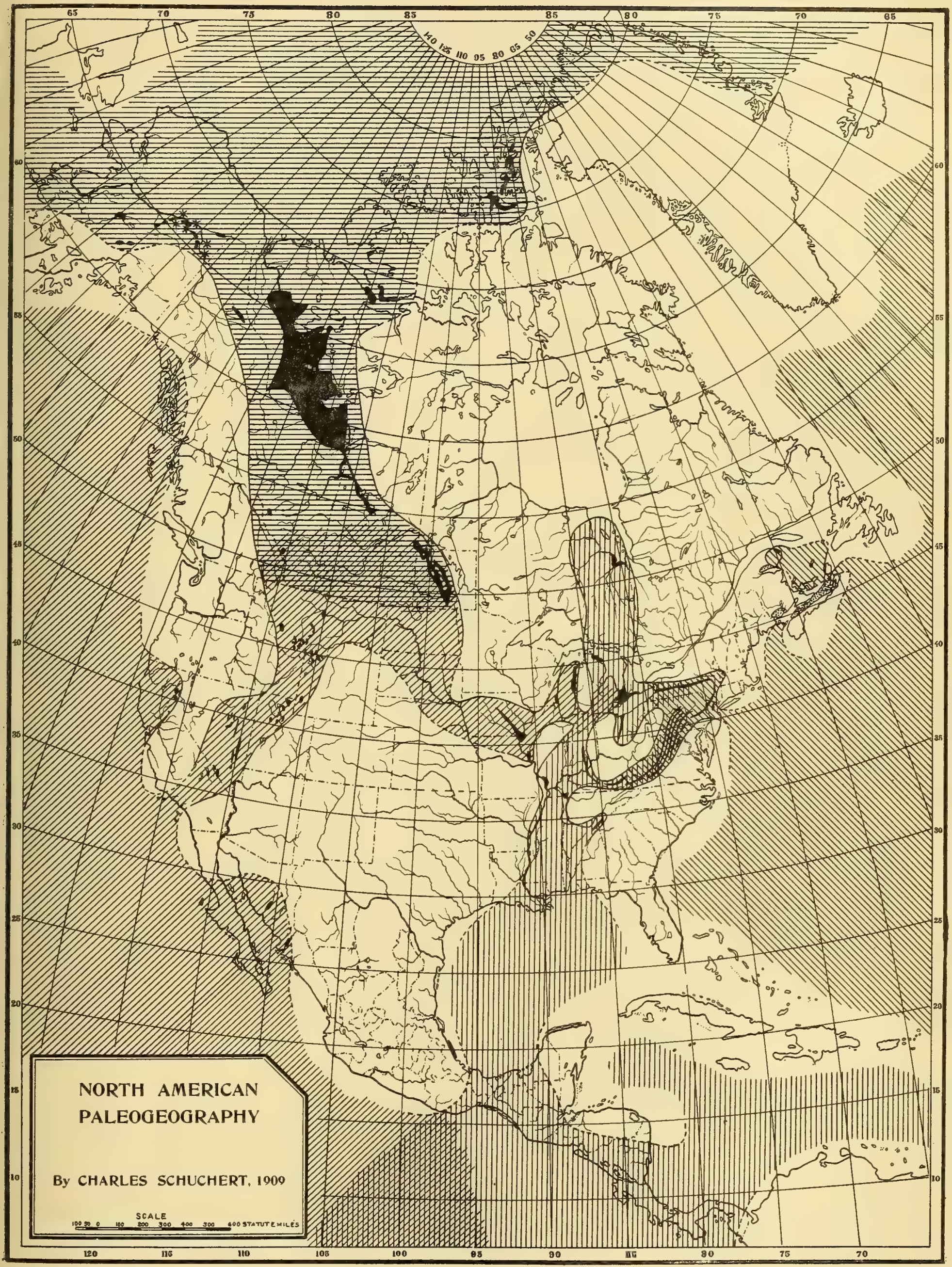
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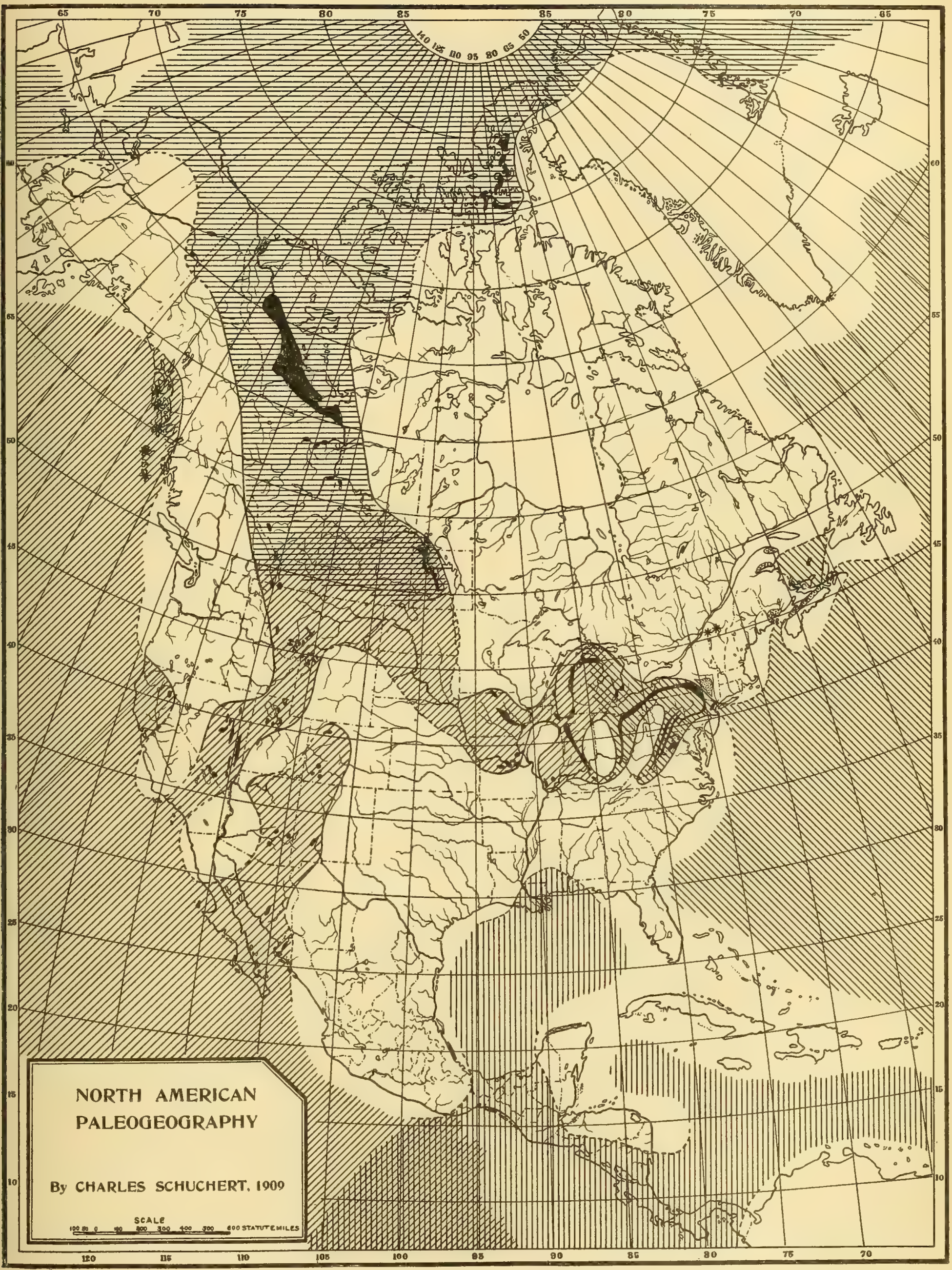
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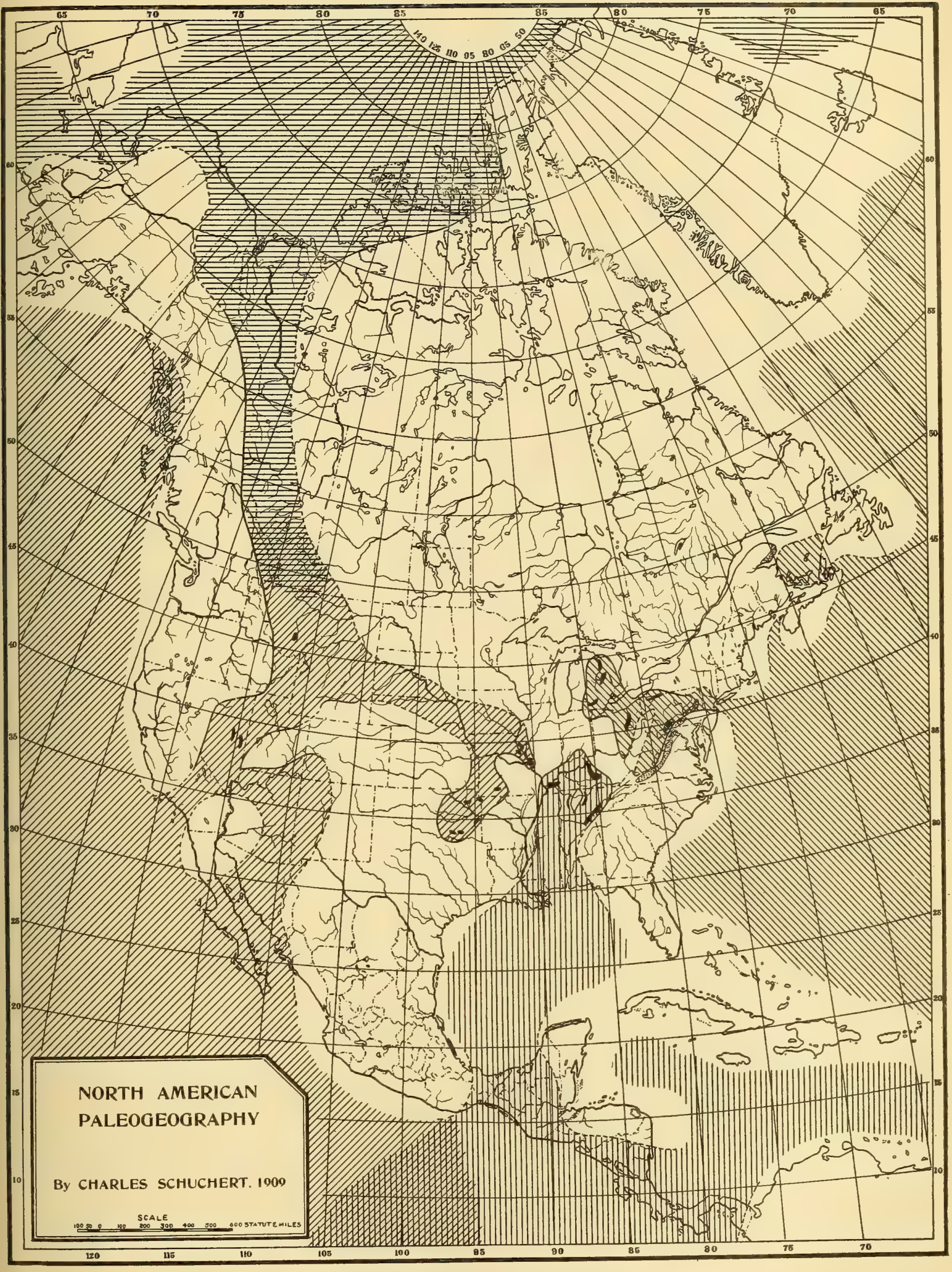
UPPER DEVONIC (ITHACA-CHEMUNG)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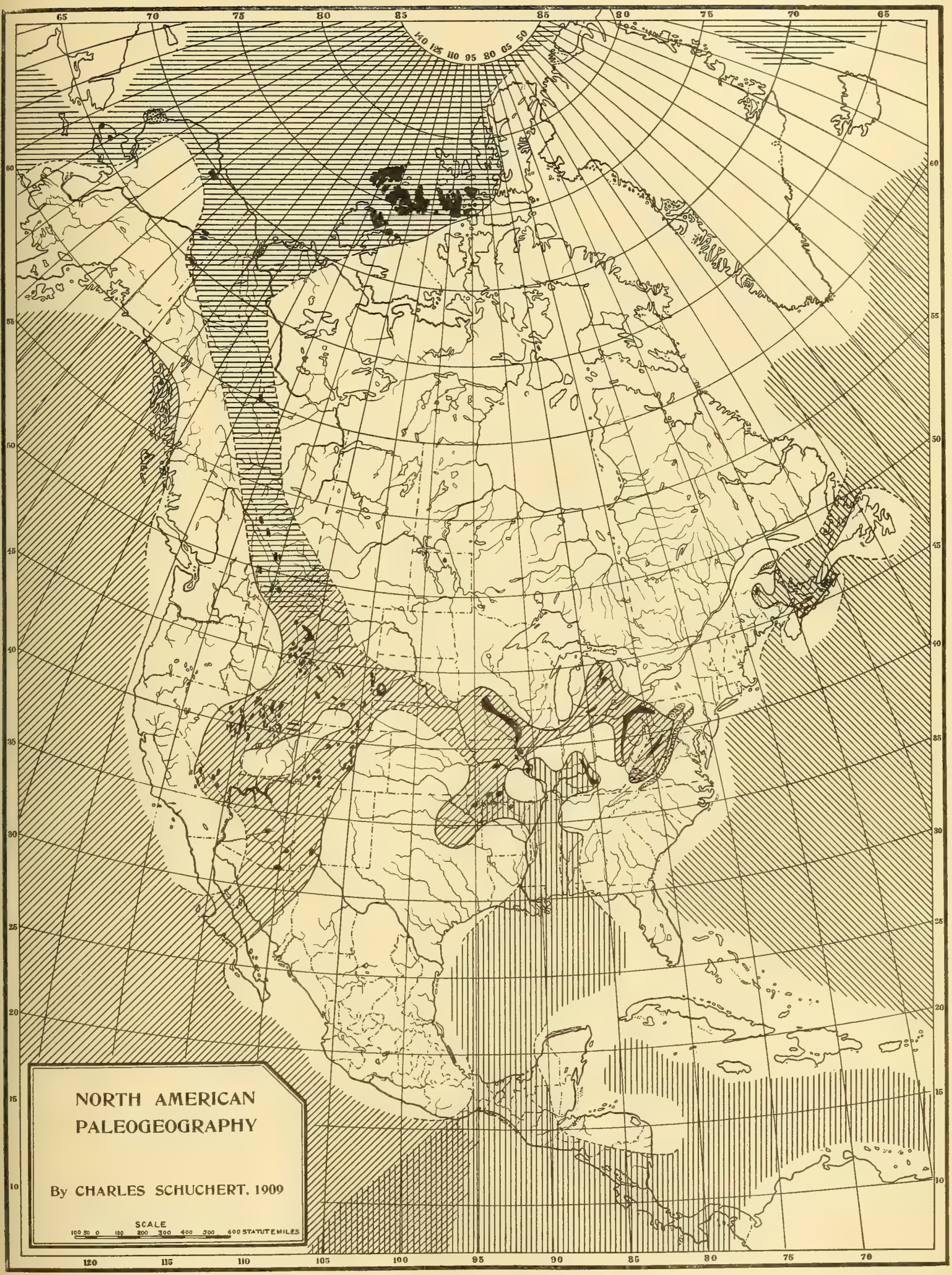
LOWER MISSISSIPPIC (BRADFORDIAN)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By CHARLES SCHUCHERT, 1909
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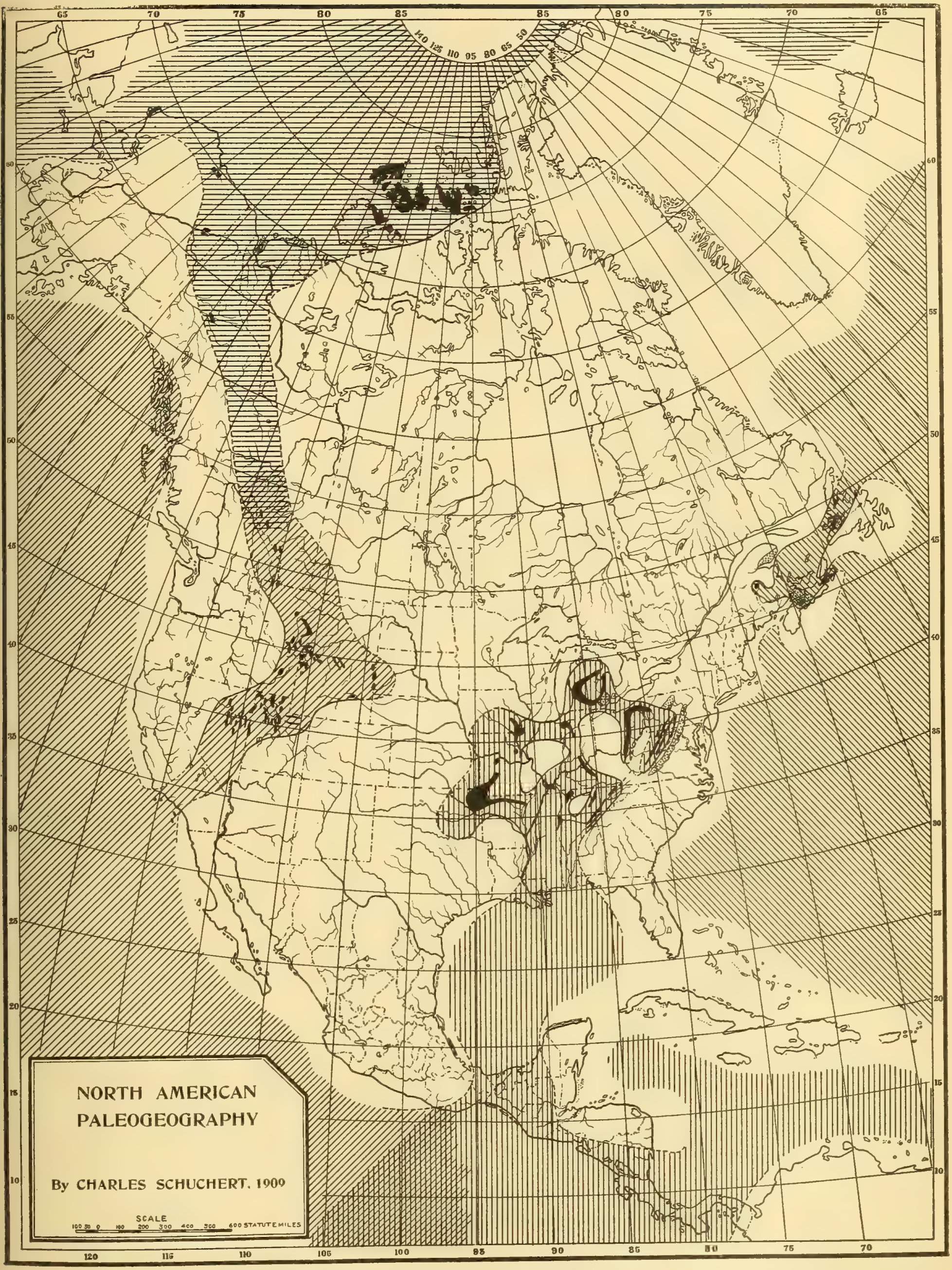
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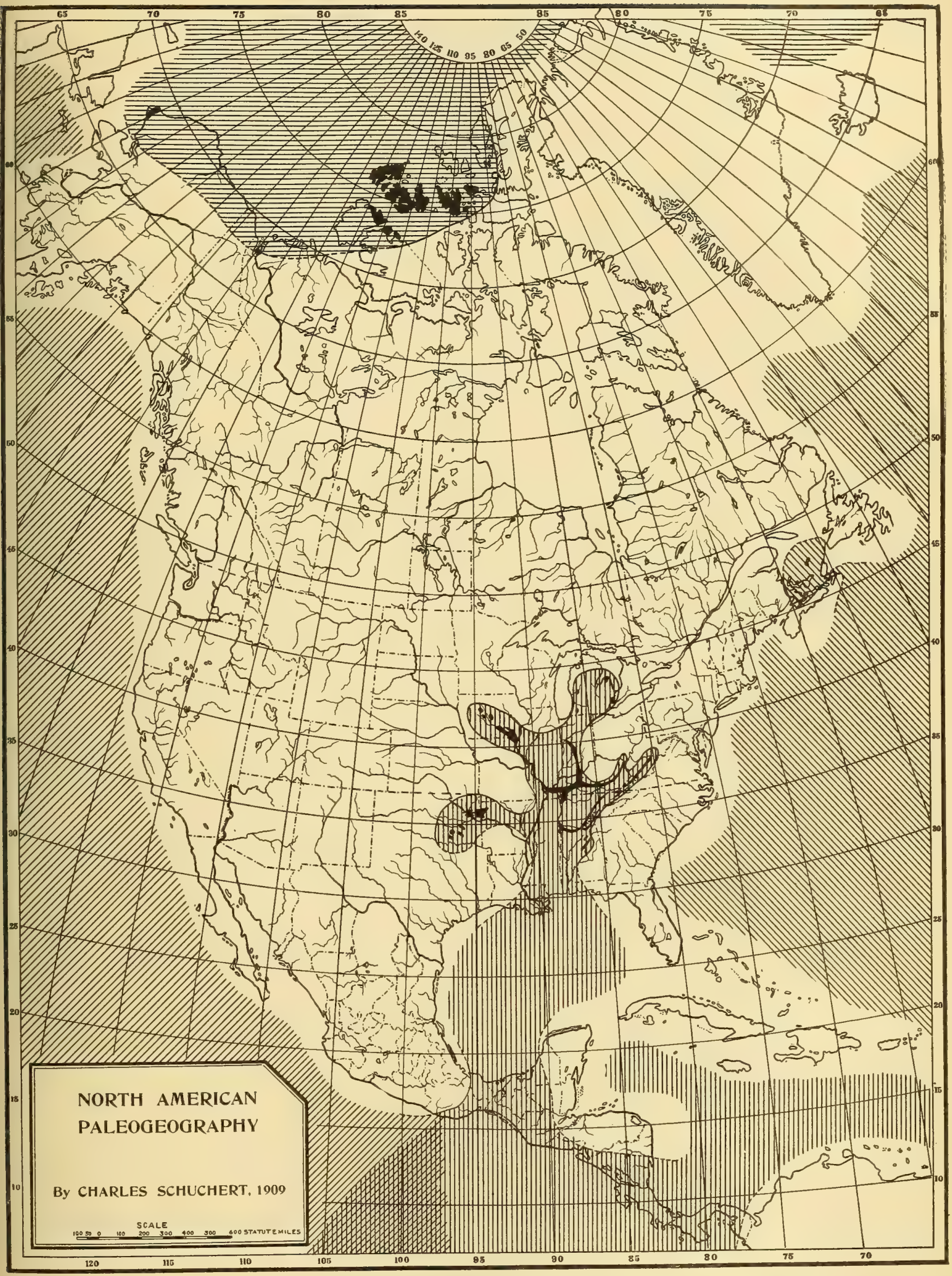
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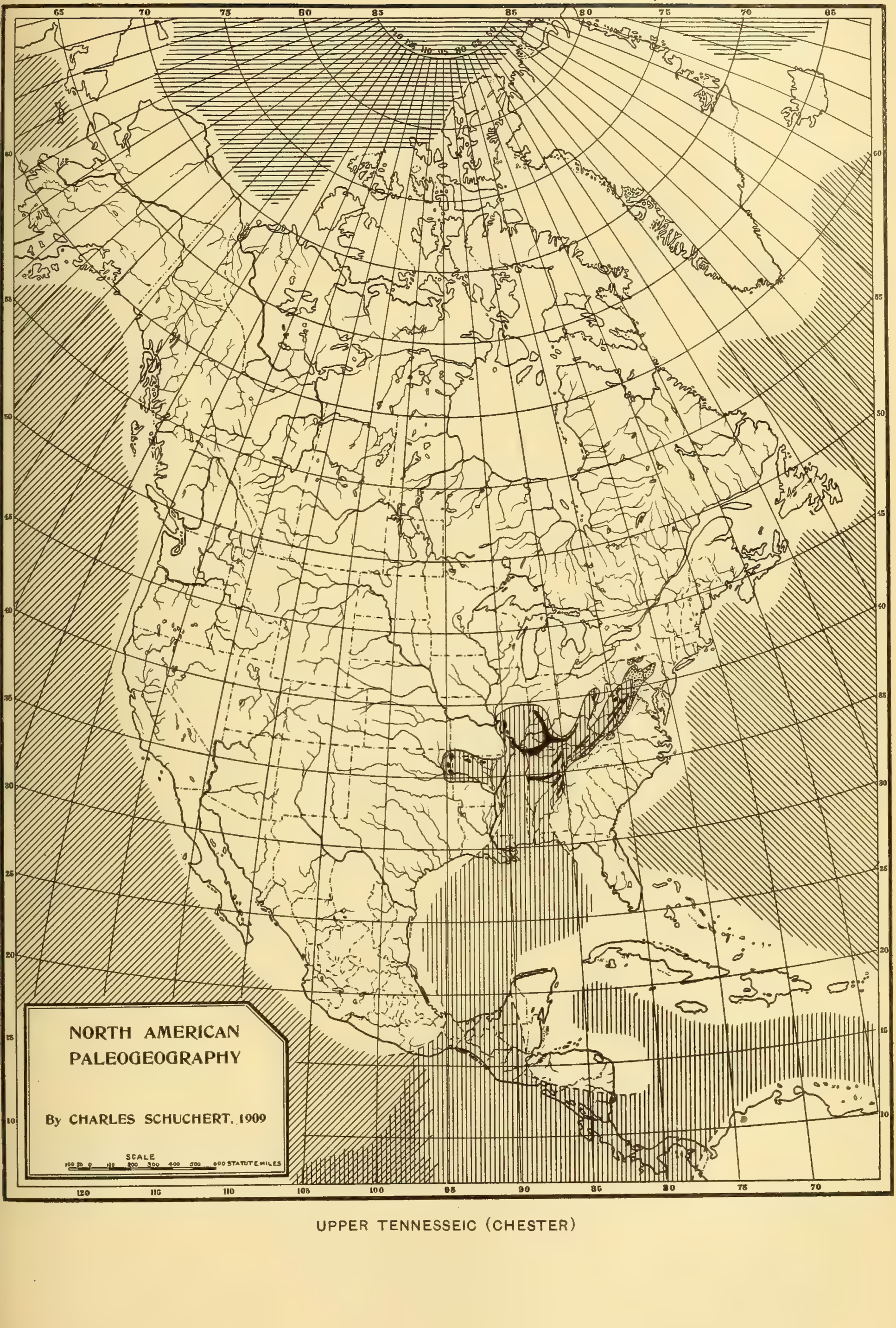
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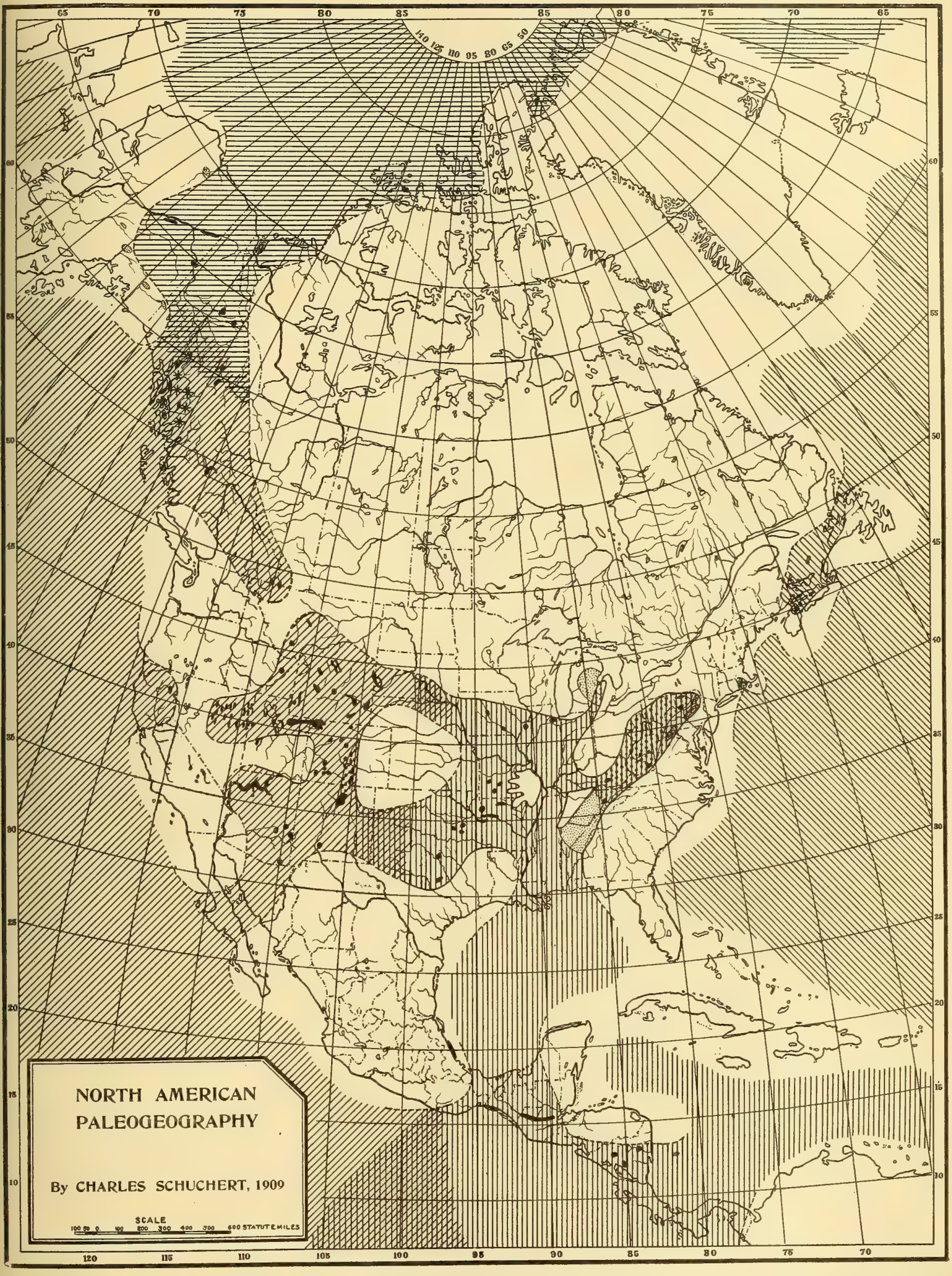
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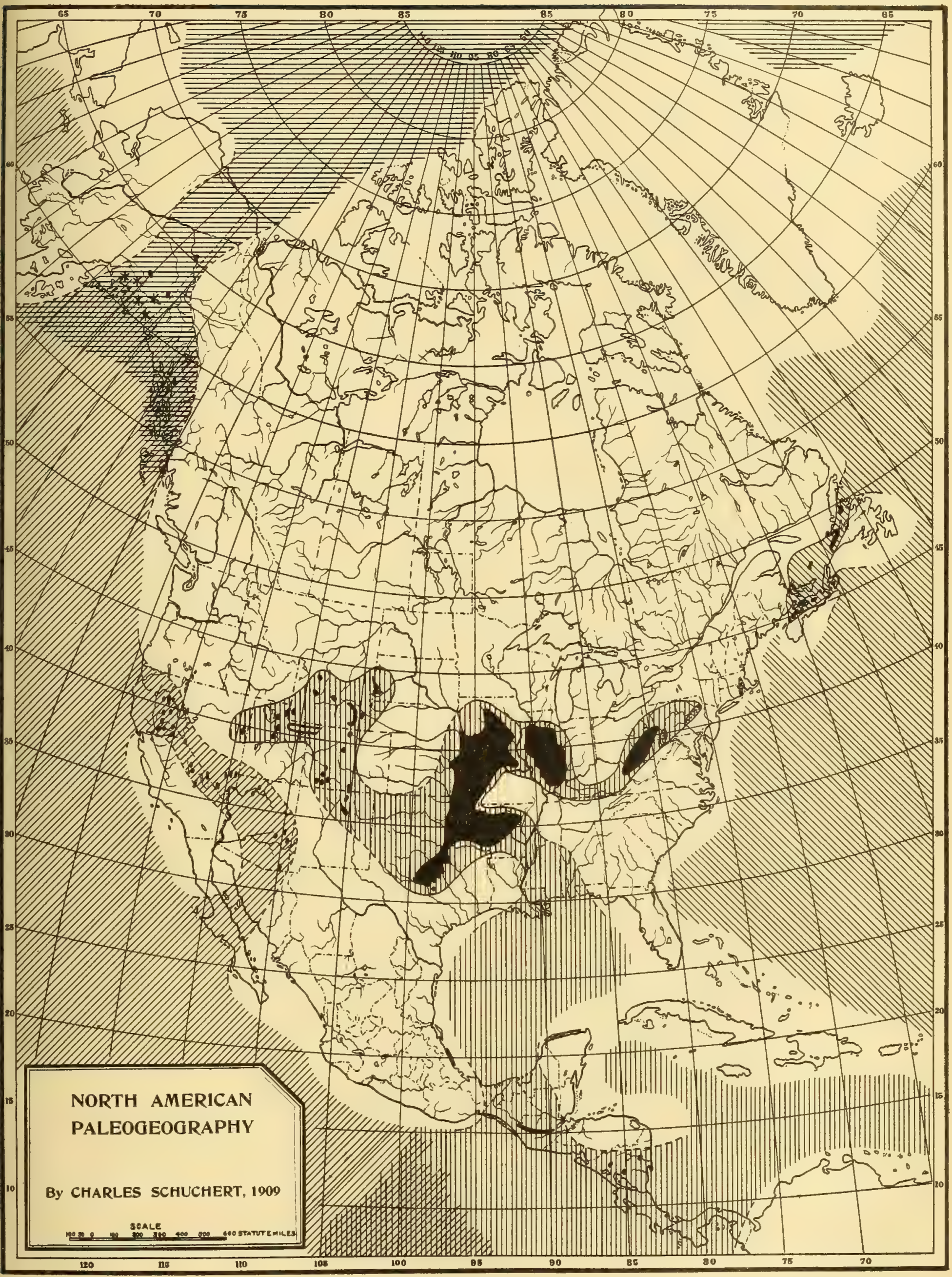
LOWER PENNSYLVANIC (UPPER POTTSVILLE)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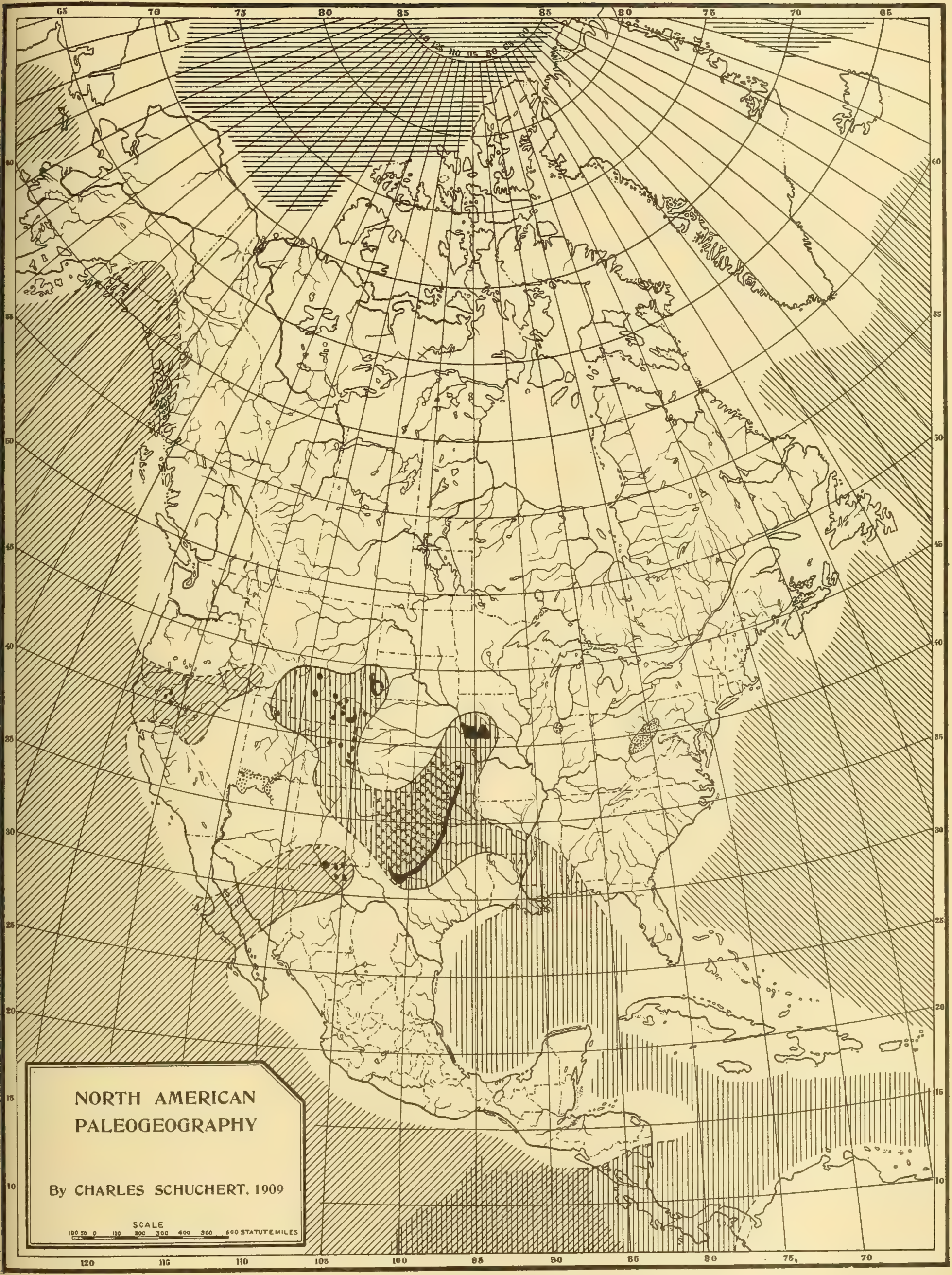
UPPER PENNSYLVANIC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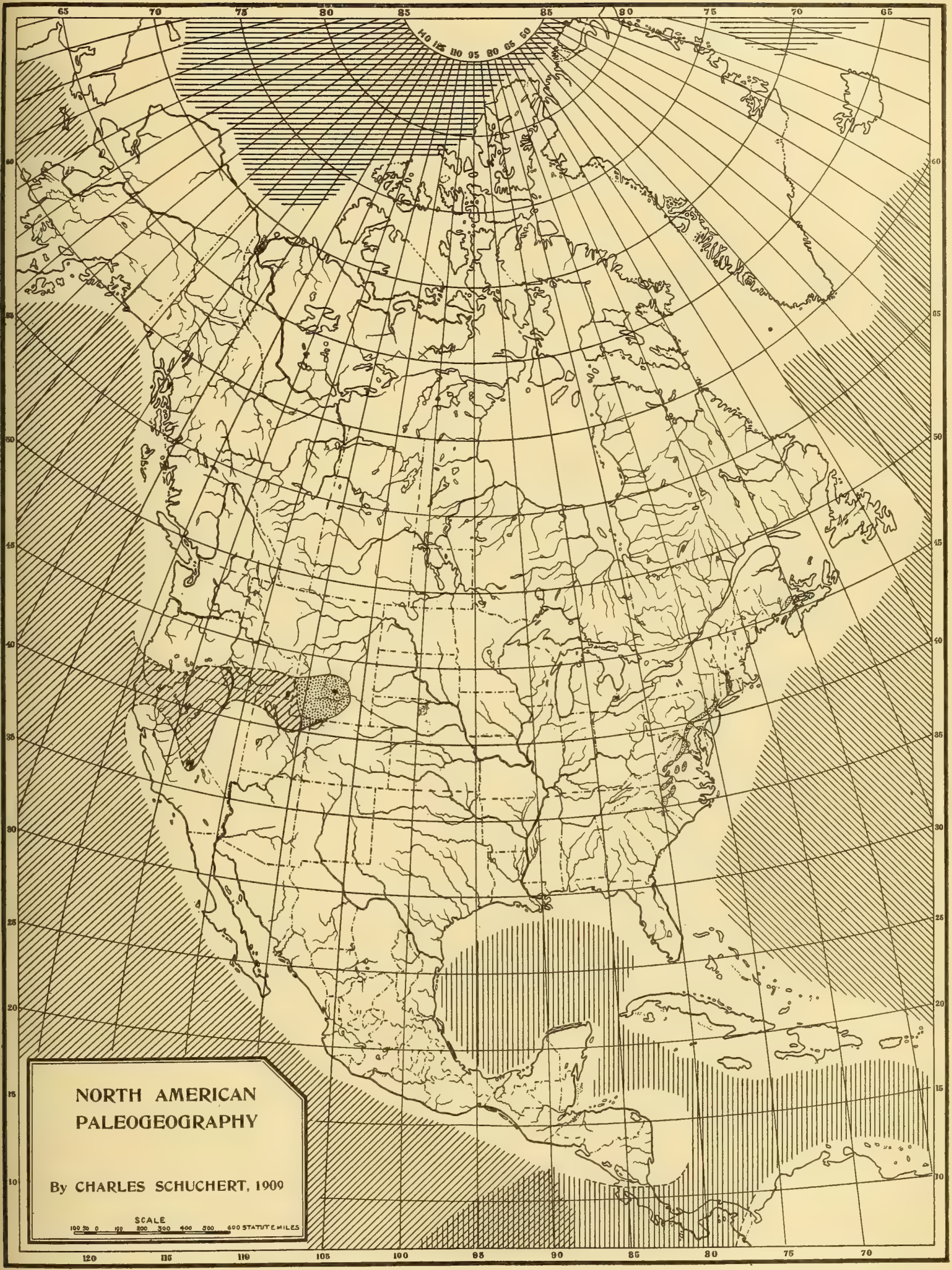
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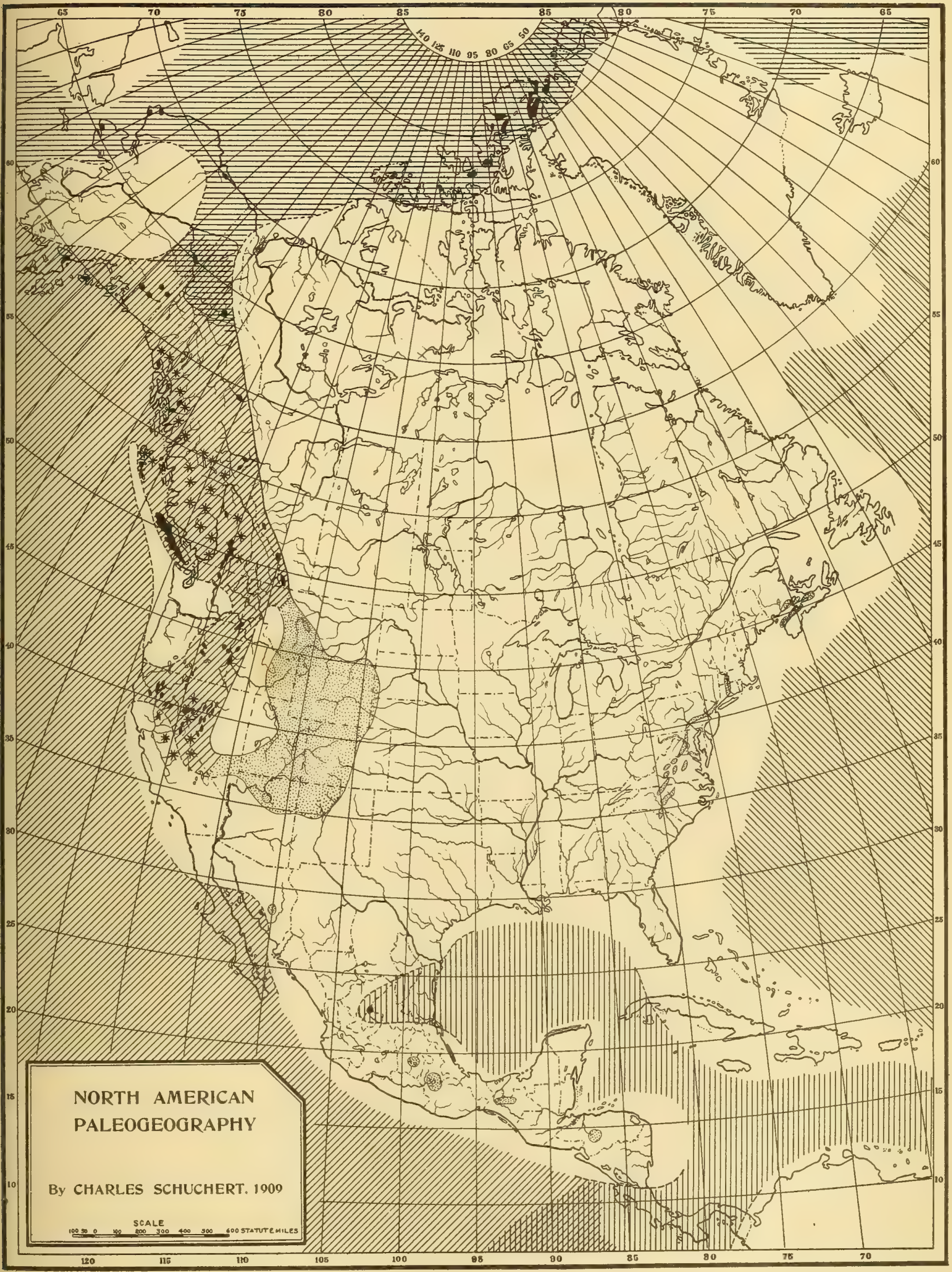
LOWER TRIASSIC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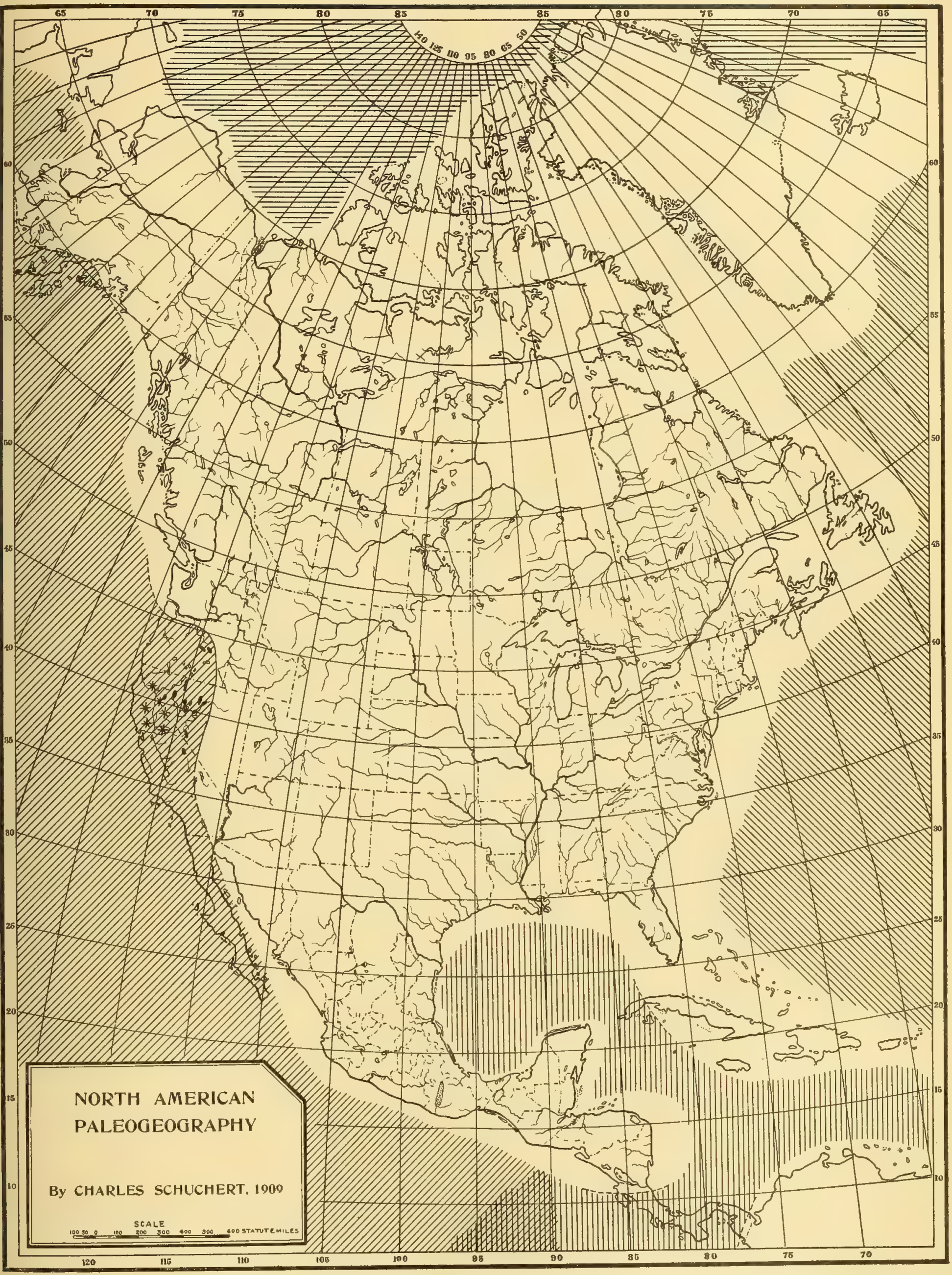
UPPER TRIASSIC (HOSSELKUS+)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By CHARLES SCHUCHERT, 1909
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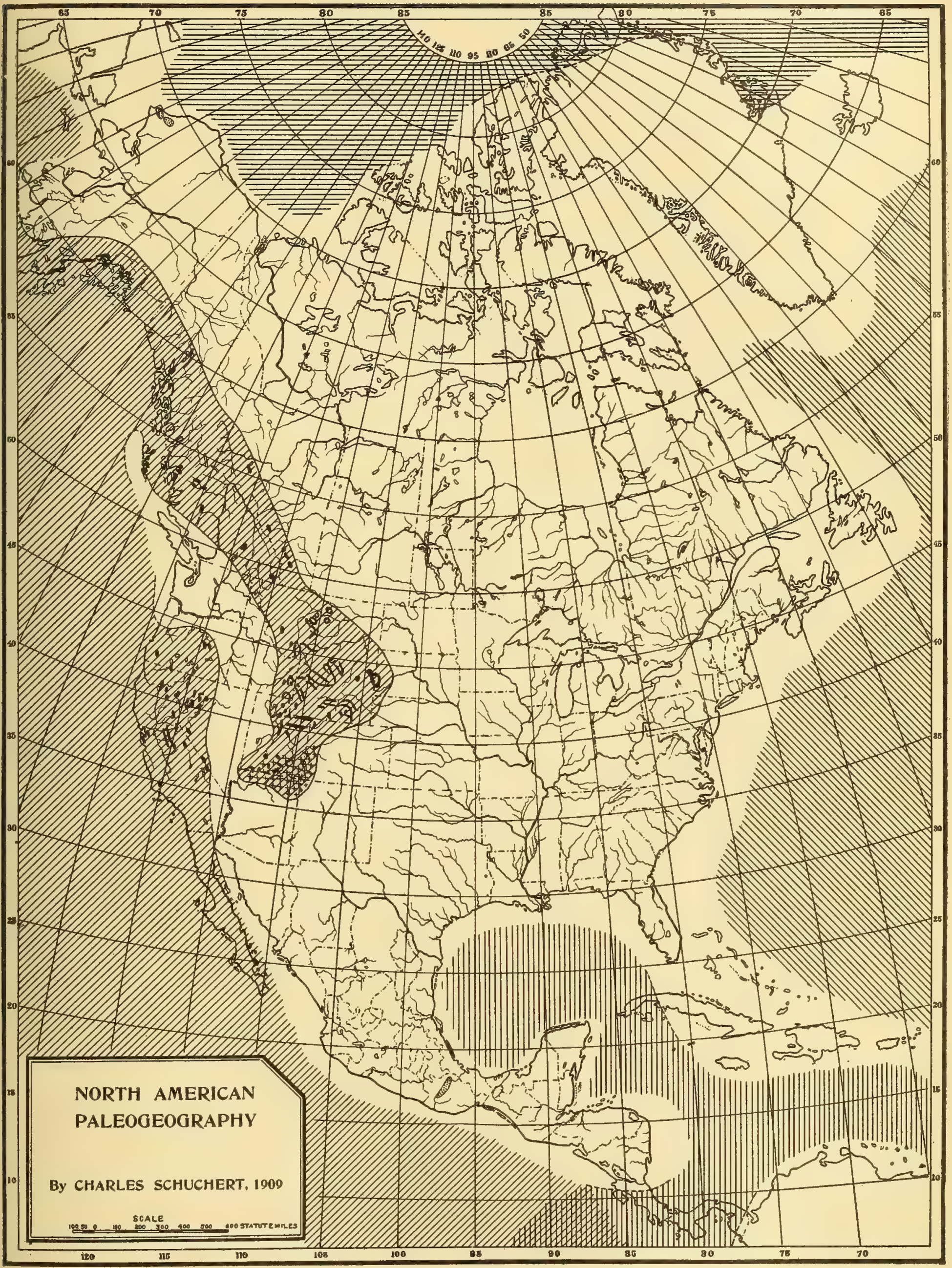
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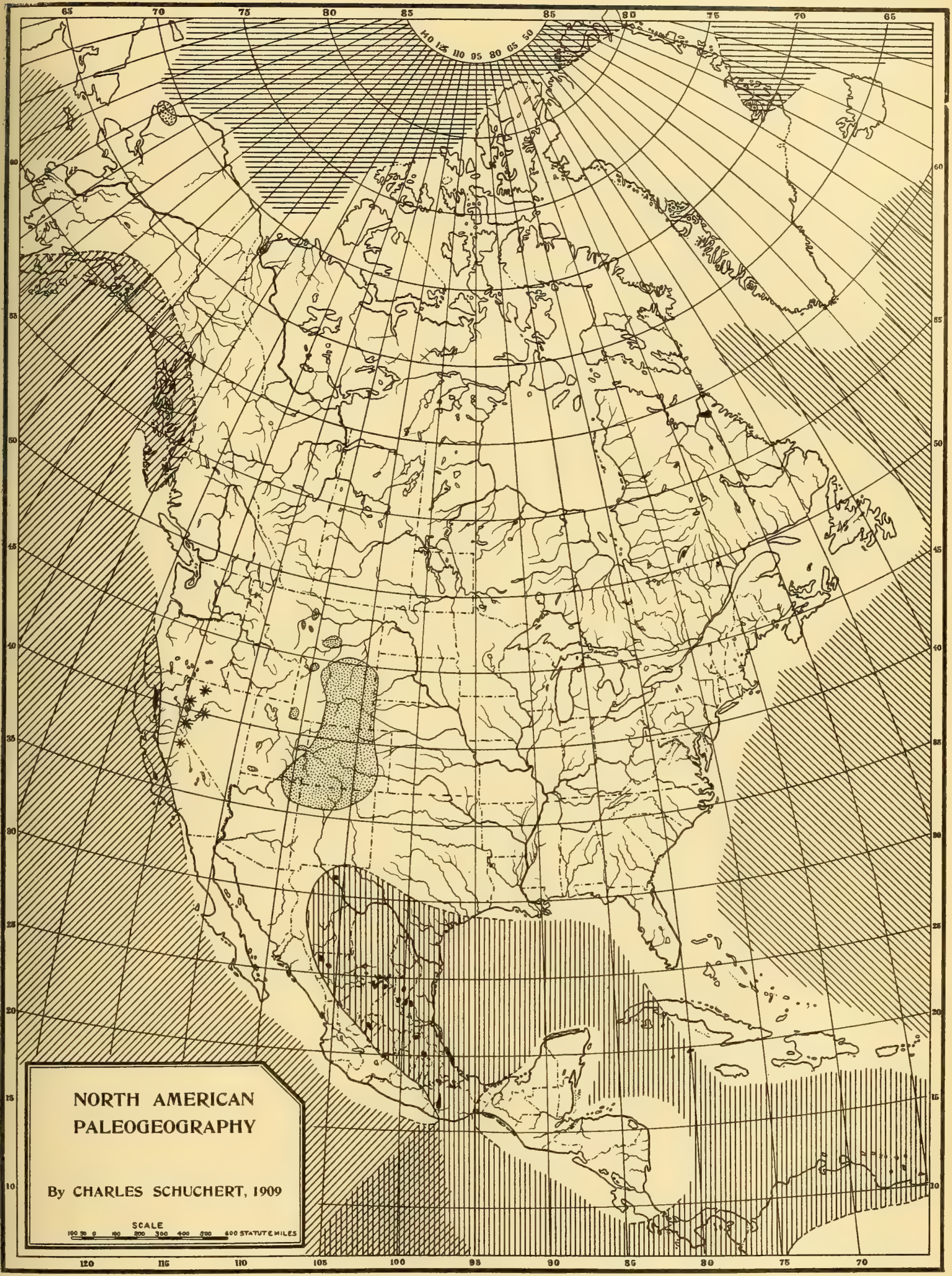
EARLY UPPER JURASSIC (SUNDANCE)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By CHARLES SCHUCHERT, 1909
SCALE
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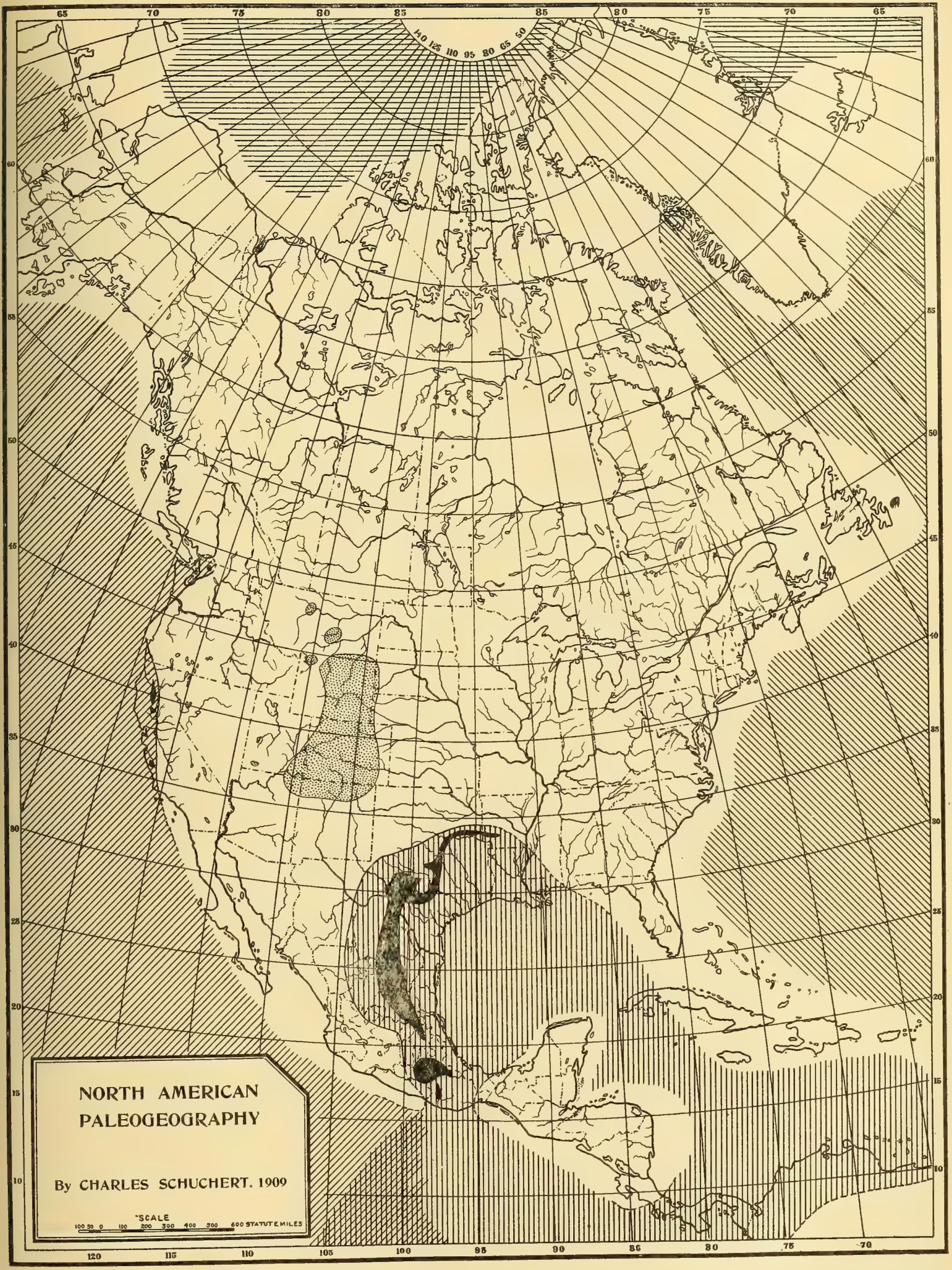
LATE UPPER JURASSIC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By CHARLES SCHUCHERT. 1909
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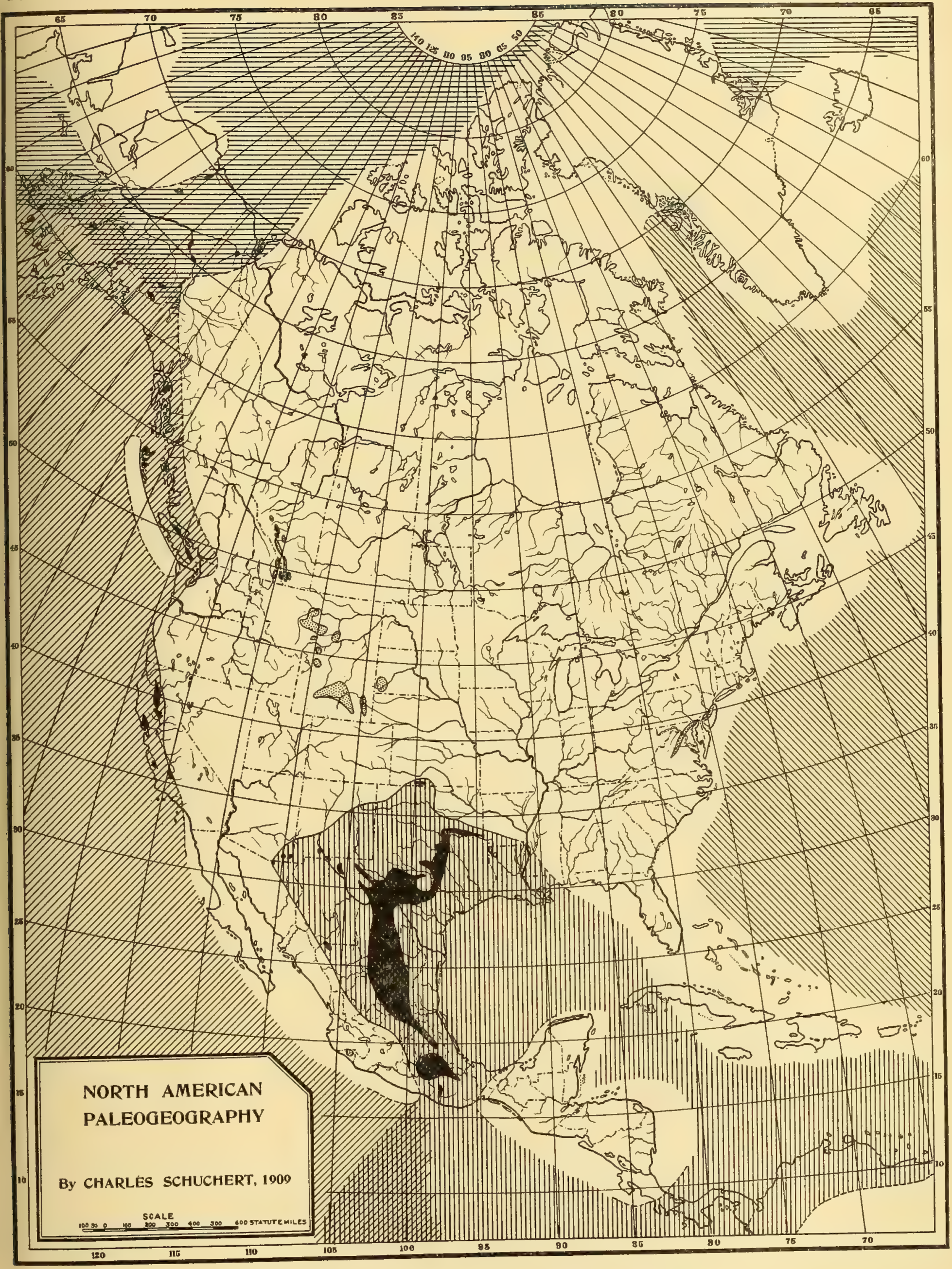
EARLY COMANCHIC (LOWER TRINITY-KNOXVILLE)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By CHARLES SCHUCHERT, 1909
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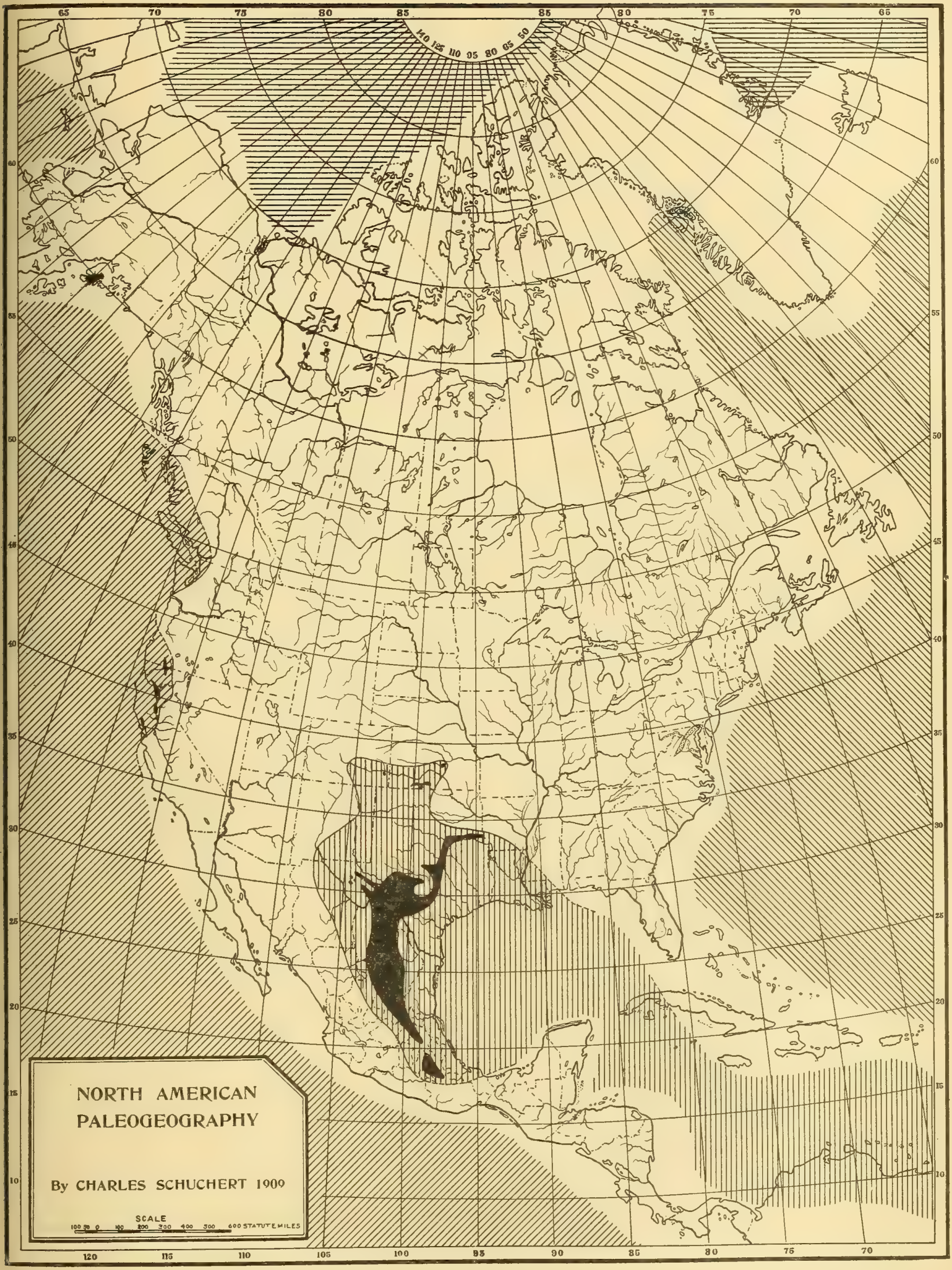
EARLY M. COMANCHIC (FREDERICKSBURG-U. KNOXVILLE)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By CHARLES SCHUCHERT 1909
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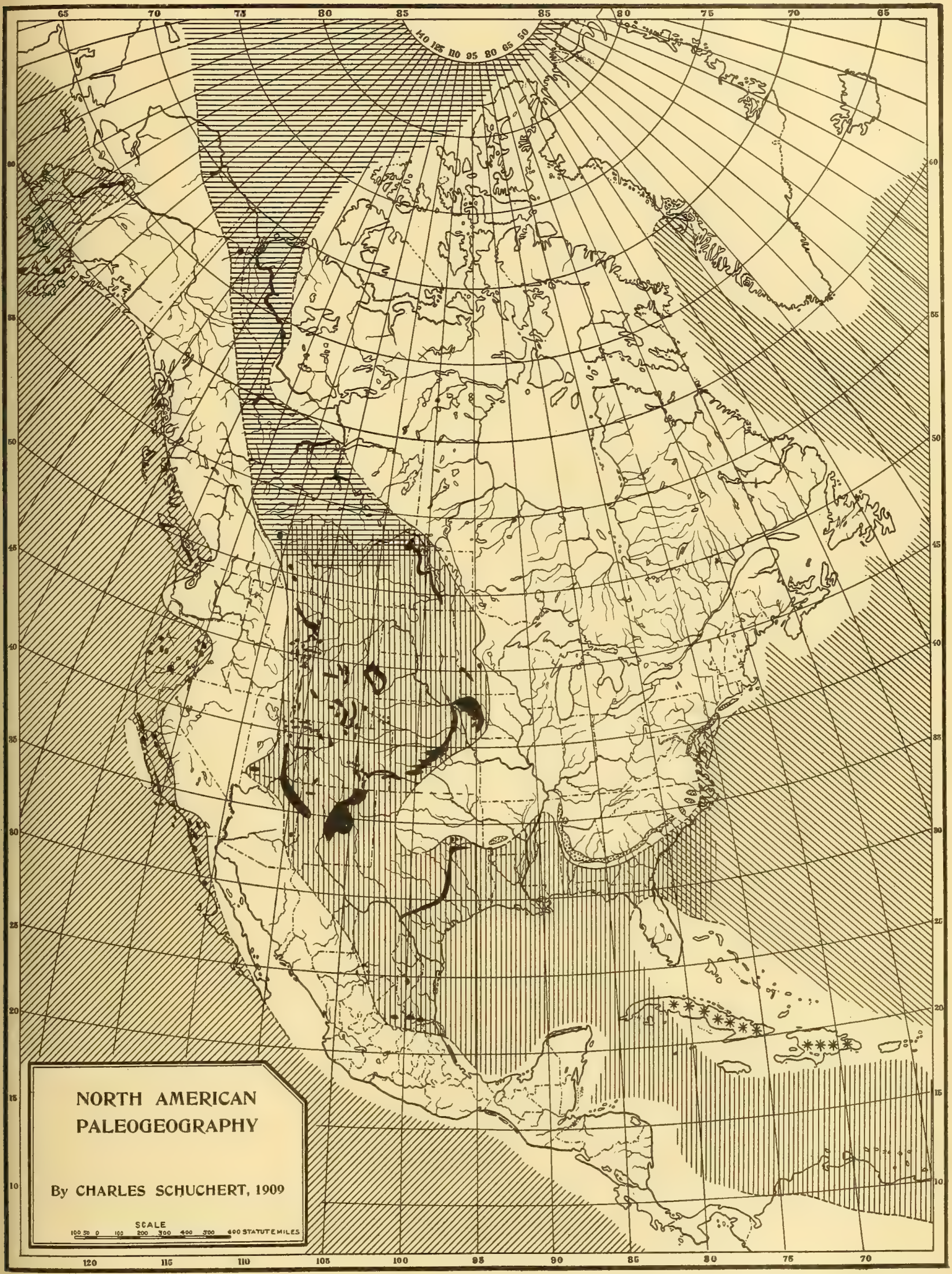
LATE COMANCHIC (UPPER WASHITA-HORSETOWN)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By CHARLES SCHUCHERT, 1909
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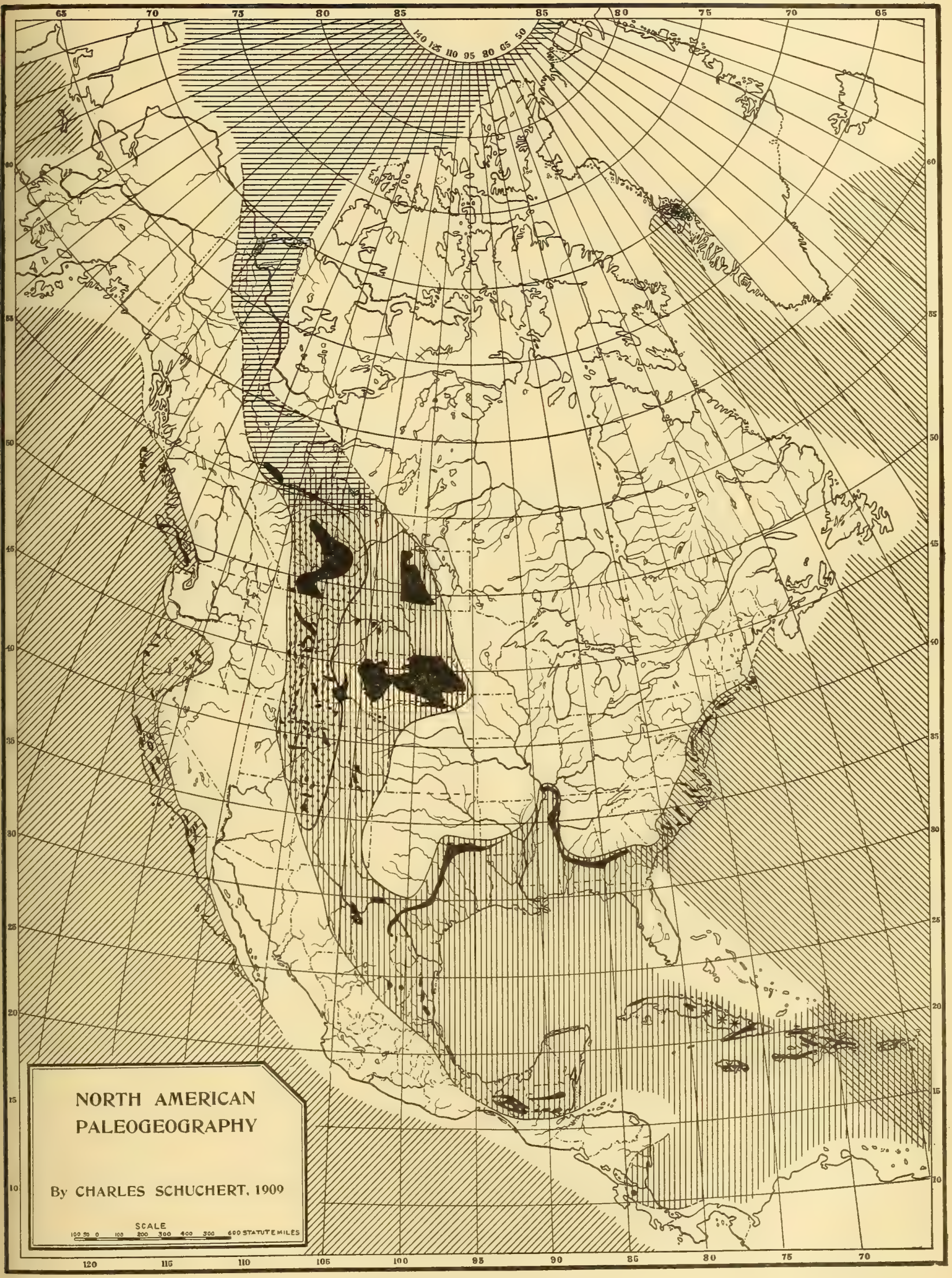
EARLY CRETACIC (BENTON)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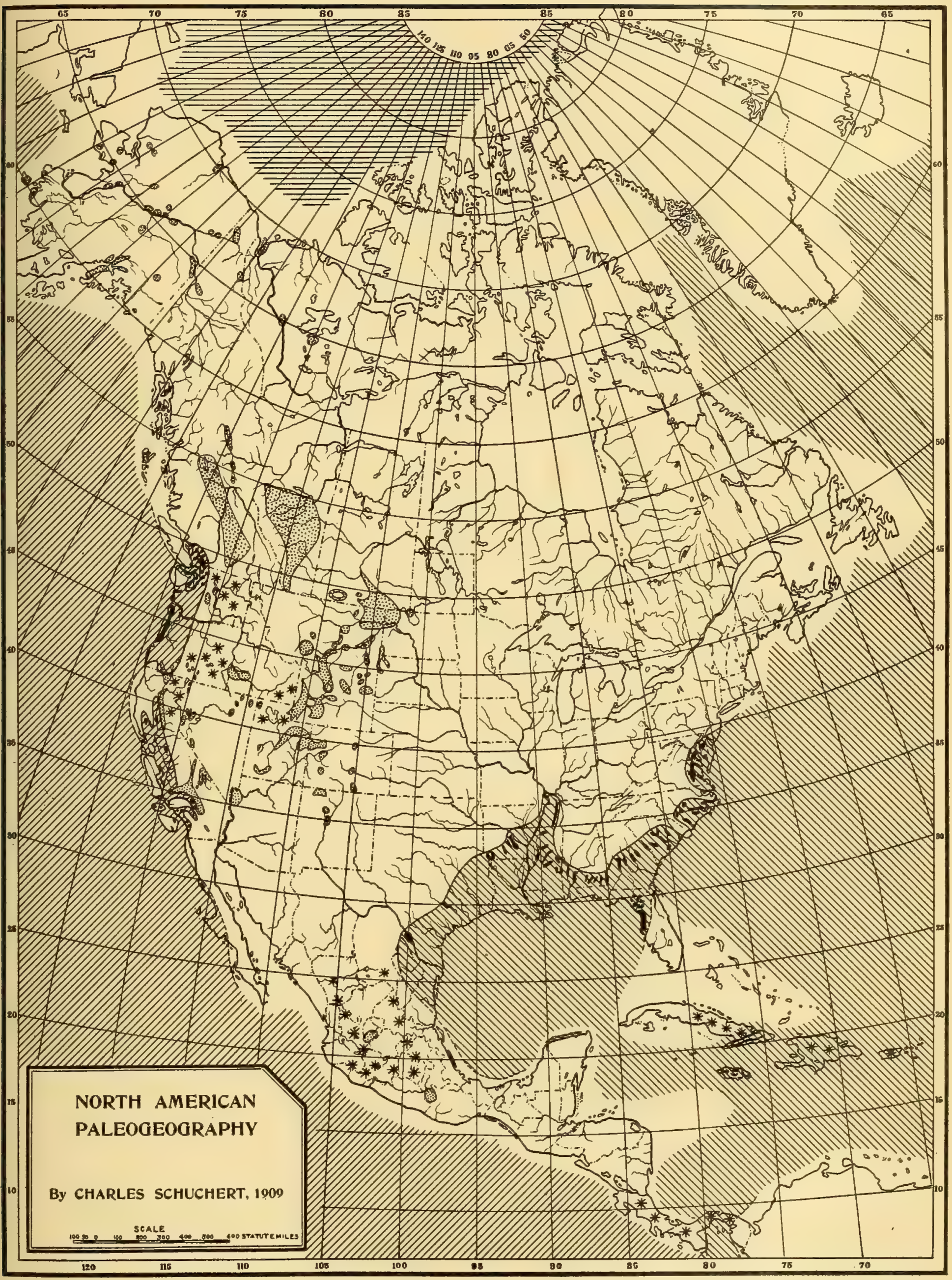
MIDDLE CRETACIC (PIERRE)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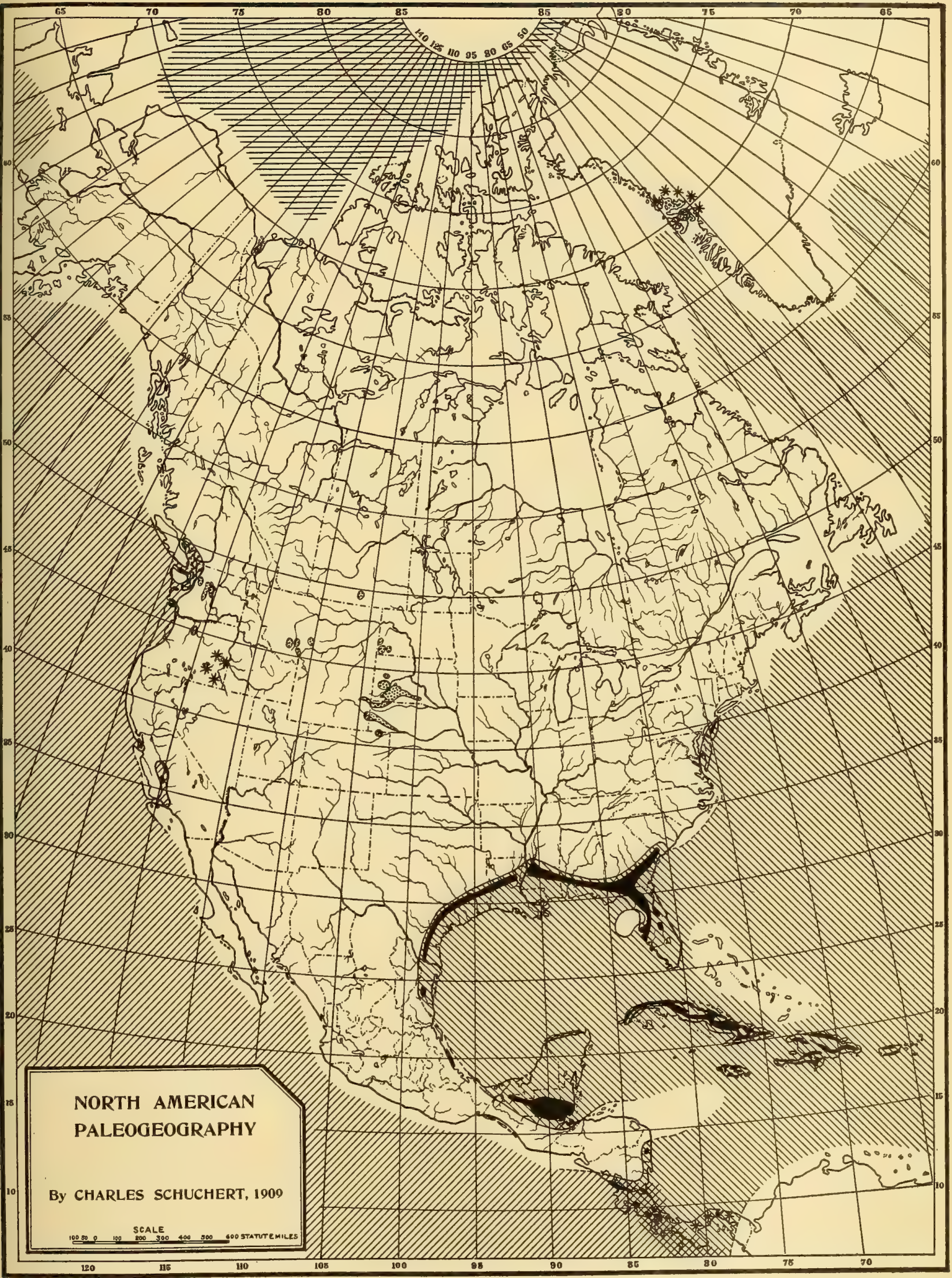
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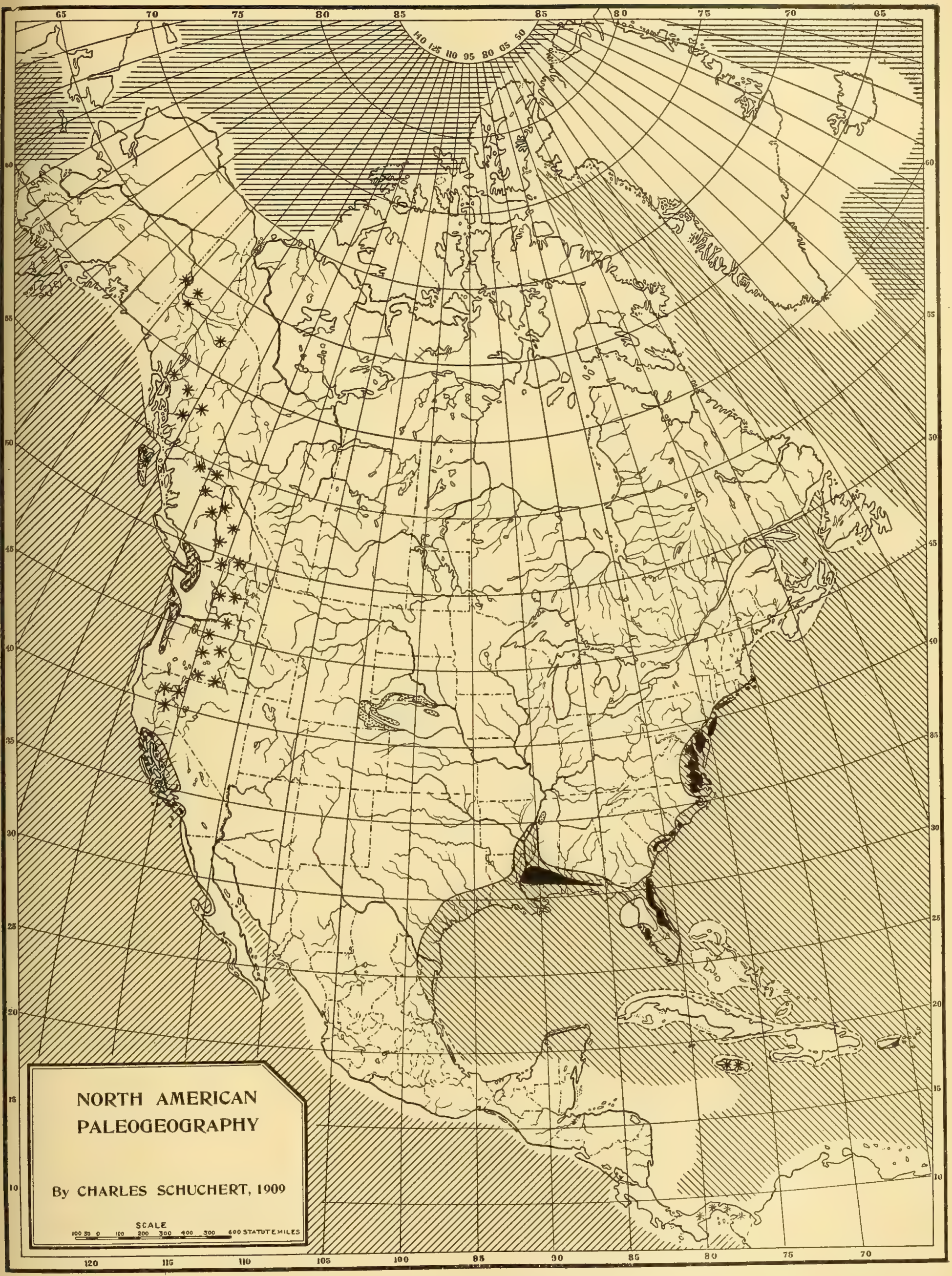
UPPER OLIGOCENE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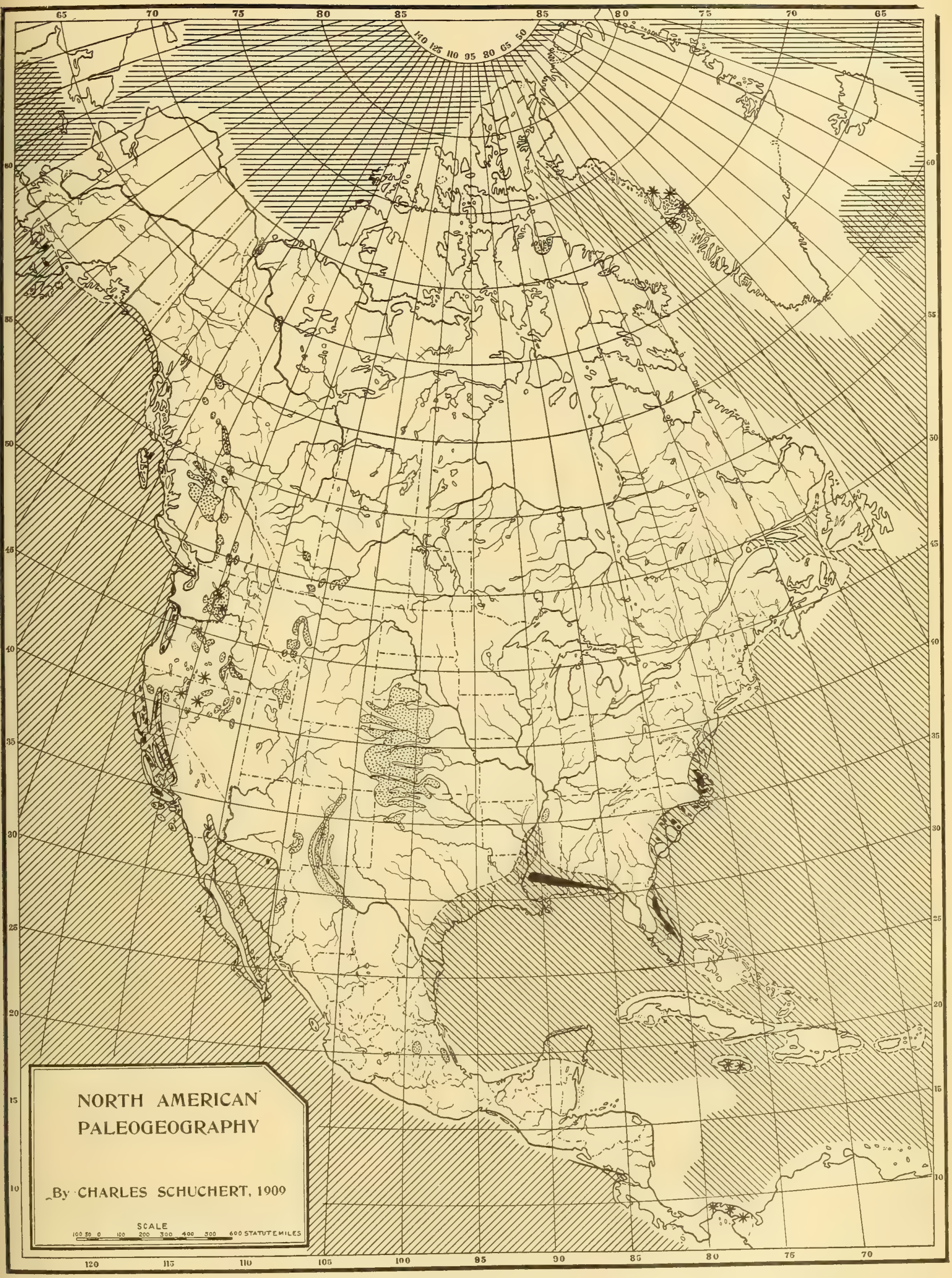
LOWER MIOCENE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By CHARLES SCHUCHERT, 1909
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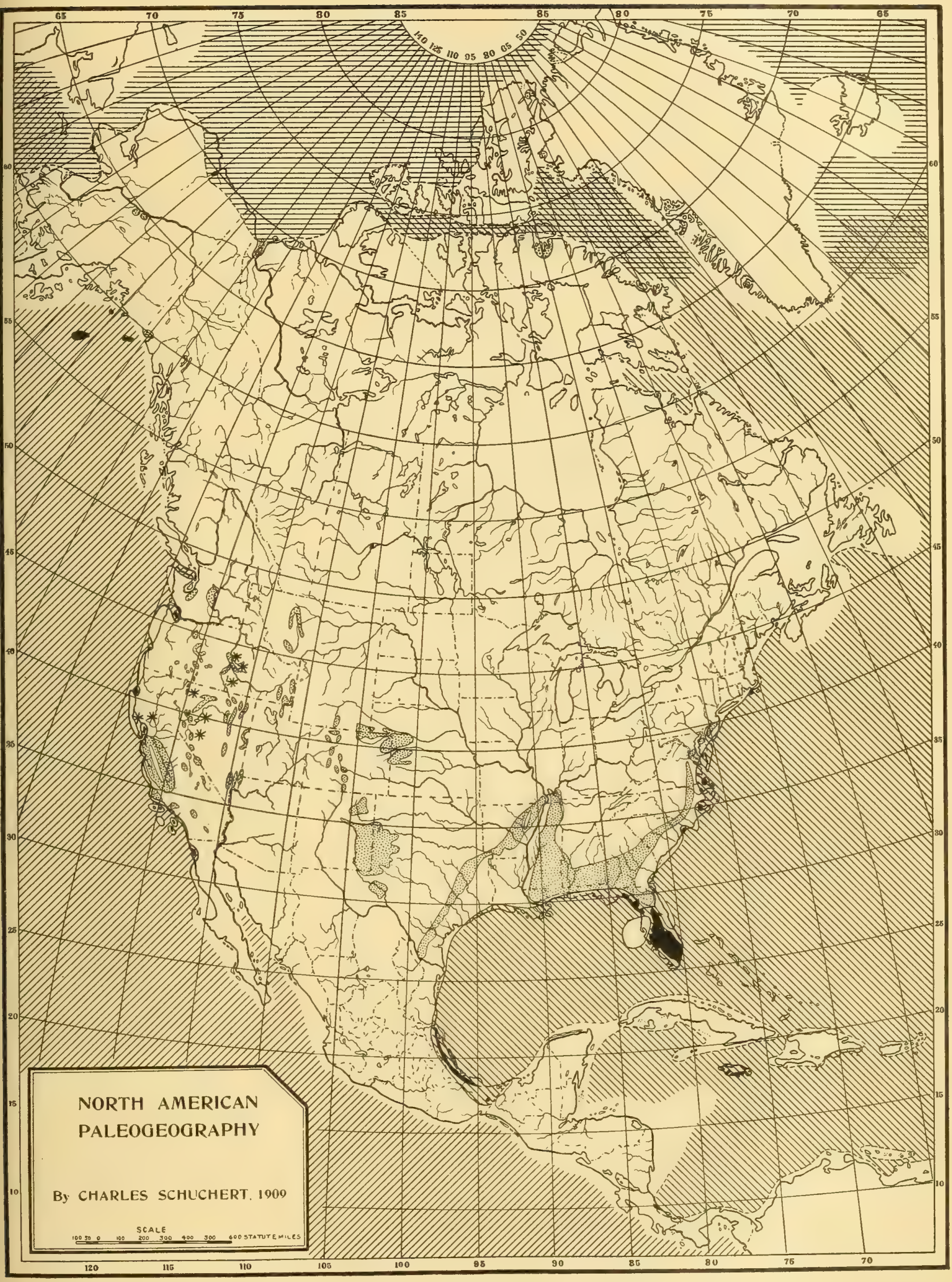
UPPER MIOCENE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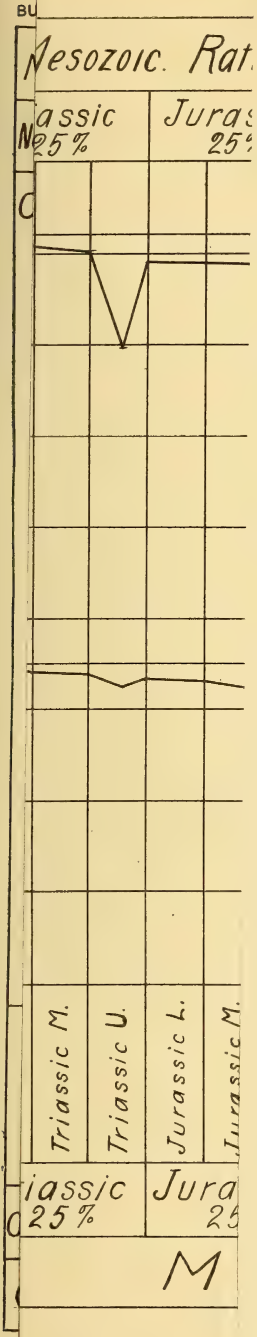
PLIOCENE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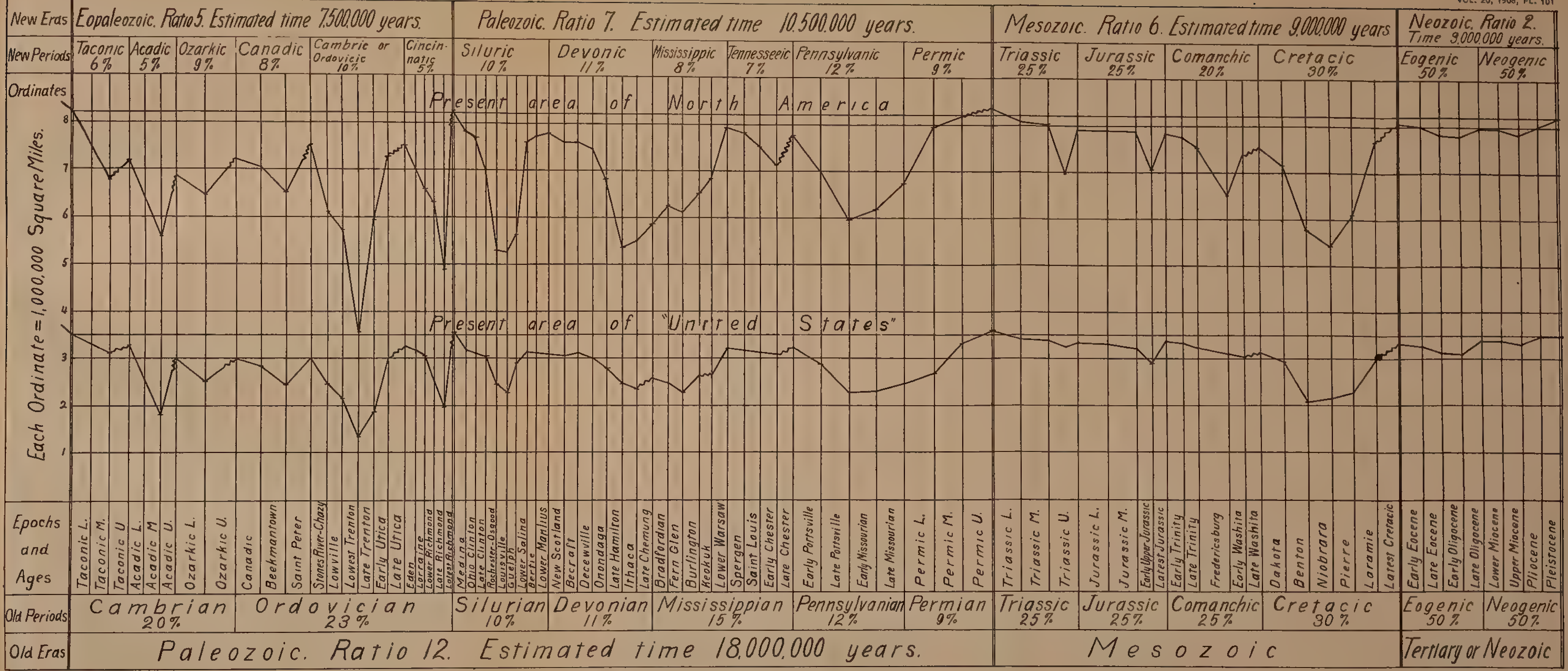

CURVES SHOWING THE AMOUNT OF SUBMERGENCES AND EMERGENCES IN TIME AND SPACE

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 20, PP. 607-749, PLS. 102-111 FEBRUARY 5, 1910

PROCEEDINGS OF THE TWENTY-FIRST ANNUAL MEETING, HELD AT BALTIMORE, MARYLAND, DECEMBER 29, 30, AND 31, 1908

EDMUND OTIS HOVEY, *Secretary*

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SESSION OF TUESDAY, DECEMBER 29

The Society was called to order at 10 A. M. with President Calvin in the chair, and was cordially welcomed to Baltimore by Professor W. B. Clark in a few well chosen remarks, to which appropriate response was made by President Calvin.

The report of the Council was called for, and was presented by the Secretary, in print, as follows:

REPORT OF THE COUNCIL

To the Geological Society of America,
in Twenty-first Annual Meeting assembled:

The regular annual meeting of the Council was held at Albuquerque, New Mexico, in connection with the meeting of the Society, December 30 and 31, 1907. There have been no special meetings during the year, but some business has been transacted by correspondence.

The details of administration for the twentieth year of the existence of the Society are given in the following reports of the officers:

SECRETARY'S REPORT

To the Council of the Geological Society of America:

Meetings.—The proceedings of the annual meeting of the Society held at Albuquerque, New Mexico, December 30 and 31, 1907, have been recorded in the closing brochure of volume 19 of the Bulletin, which is now in press.

Membership.—During the past year the Society has lost two Fellows by death: Homer T. Fuller and William S. Yeates, and two by resignation. The names of the four Fellows elected at the Albuquerque meeting have been added to the list, all of them having completed their membership according to rule. The present enrollment of the Society is 294, the same as at the time of making the last annual report. Fourteen candidates are before the Society for election, and several applications are under consideration by Council.

Distribution of Bulletin.—There have now been distributed 16 brochures, comprising 346 pages, of volume 19, and the remaining 6 brochures, including the Proceedings, are in the hands of the printers in various stages of completion. By action of the Publication Committee no manuscripts were accepted by the Secretary after October 1, in an effort to finish the volume within the calendar year. With this arrangement the volume could have been completed as desired if the authors had been more prompt in returning the corrected proofs.

The irregular distribution of the Bulletin during the past year has been as follows: Complete volumes, including one complete set, sold to Fellows, 20; sold to the public, including one complete set, 166; sent out to supply delinquents, 2; brochures sent out to supply deficiencies and delinquents, 106; sold to Fellows, 37; sold to the public, 42. Three copies of volume 18 have been bound for the use of officers and the library, and one has been bound and presented to Dr I. C. White by order of the Council.

Bulletin Sales.—The receipts from the sale of the Bulletin during the past year are shown in the following table:

Bulletin Sales, December 1, 1907, to December 1, 1908

	Complete volumes.			Brochures.			Grand total.
	Fellows.	Public.	Total.	Fellows.	Public.	Total.	
Volume 1	$4.50	$10.00	$14.50	$1.00	$1.60	$2.60	$17.10
Volume 2	4.50	10.00	14.50	....	1.15	1.15	15.65
Volume 3	4.00	15.00	19.00	.20	....	.20	19.20
Volume 4	3.50	15.00	18.50	....	.30	.30	18.80
Volume 5	4.00	10.00	14.00	.30	.45	.75	14.75
Volume 6	4.00	10.00	14.00	.60	1.55	2.15	16.15
Volume 7	4.00	10.00	14.00	.25	1.00	1.25	15.25
Volume 8	4.00	10.00	14.00	....	.35	.35	14.35
Volume 9	4.00	10.00	14.00	....	1.20	1.20	15.20
Volume 10	4.00	10.00	14.00	.10	.20	.30	14.30
Volume 11	4.50	15.00	19.50	.50	.55	1.05	20.55
Volume 12	4.00	20.00	24.00	1.00	....	1.00	25.00
Volume 13	4.50	20.00	24.50	1.20	....	1.20	25.70
Volume 14	4.50	30.00	34.50	.30	1.20	1.50	36.00
Volume 15	9.00	45.00	54.00	.95	1.10	2.05	56.05
Volume 16	9.00	35.00	44.00	.90	.75	1.65	45.65
Volume 17	10.00	70.00	80.00	5.40	2.85	8.25	88.25
Volume 18	....	160.00	160.00	2.65	2.95	5.60	165.60
Volume 19	....	300.00	300.00	.20	.90	1.10	301.10
Volume 20	....	37.50	37.50	....	....	....	37.50
Total	$86.00	$842.50	$928.50	$15.55	$18.10	$33.65	$962.15
Index	4.50	5.00	9.50	....	....	....	9.50
	$90.50	$847.50	$938.00	$15.55	$18.10	$33.65	$971.65
Deductions:							
Net loss on foreign exchange						0.21	
Clerical error in transmission						.05	
							.26
							$971.39

Receipts for the fiscal year	$971.39
Previously reported	10,274.12
Total receipts to date	$11,245.51
Charged, but not yet received:	
On 1908 account	17.00
Total sales to date	$11,262.51

The bills for volume 19 have not yet been sent out to volume subscribers who do not pay in advance, and the table given above includes only actual payments.

The cost of publishing the Bulletin, volumes 1-18, has been $33,414.91, the average cost per volume being $1,995.38. These figures, however, do not include the expense of distribution. The number of pages and illustrations in the volumes has increased so much during the past few years that the price of subscription for libraries and foreign individuals has been raised to $7.50 by vote of Council.

Expenses.—The following table gives the cost of administration and of Bulletin distribution during the past year:

EXPENDITURE OF SECRETARY'S OFFICE DURING THE FISCAL YEAR ENDING NOVEMBER 30, 1908

Account of Administration

Postage and telegrams	$64.14	
Express	6.55	
Stationery and printing	168.30	
Addressograph plates	2.34	
Traveling	6.50	
Laborer	.55	
Expenses of Cordilleran Section	2.50	
Total		$250.88

Account of Bulletin

Postage	$130.48	
Express	37.76	
Collection of checks	1.85	
Laborer	4.25	
Stationery and printing	45.68	
Refund of overpayment on Bulletin	5.00	
Total		225.02
Total expenses for the year		$475.90

Respectfully submitted.

EDMUND OTIS HOVEY,
Secretary.

NEW YORK, *December 17, 1908.*

TREASURER'S REPORT, 1908

To the Council of the Geological Society of America:

The Treasurer herewith submits his annual report for the year ending December 1, 1908:

Two (2) Fellows, J. S. Diller and G. C. Martin, have commuted for life during the year by the payment of one hundred dollars each, thus increasing the total Life Commutations to eighty-five (85), which, with four (4) Honorary Life Members, makes a total of eighty-nine (89), of whom eighty-one (81) are now living.

One (1) Fellow is delinquent for four years, five (5) Fellows are delinquent for three years, eight (8) Fellows are delinquent for two years, and are therefore liable to be dropped from the roll for non-payment of dues, in accordance with section 3, chapter 1, of the By-laws; seventeen (17) Fellows are delinquent for the present year.

The membership of the Society, including delinquents, aggregates at the present time 294, of whom 81 have commuted for life. There have been two resignations and two deaths during the past year.

With the advice of the Investment Committee, the Treasurer bought during the year a one thousand dollar bond of the Saint Louis, Iron Mountain and Southern railroad, at a cost of $979.09.

RECEIPTS

Balance in treasury December 1, 1907		$1,434.15	
Fellowship fees 1904 (1)	$10.00		
" " 1905 (4)	40.00		
" " 1906 (8)	80.00		
" " 1907 (32)	320.00		
" " 1908 (182)	1,820.00		
" " 1909 (2)	20.00		
		2,290.00	
Initiation fees (4)		40.00	
Life commutations (2)		200.00	
Interest on investments:			
Iowa Apartment House Company	$60.00		
Ontario Apartment House Company	200.00		
Texas and Pacific Railroad bonds	100.00		
U. S. Steel Corporation bonds	150.00		
Saint Louis, Iron Mountain and Southern Railroad bond	50.00		
Interest on deposits in Baltimore Trust Company	36.06		
		596.06	
Sales of publications		971.39	
"Author's corrections" (paid by authors)		36.60	
Collection charges added to checks		.35	
			$5,568.55

EXPENDITURES

Secretary's office:		
Administration	$250.88	
Bulletin	229.27	
Secretary's allowance	500.00	
		$980.15
Treasurer's office:		
Postage, safe deposit box, etcetera	$27.23	
Treasurer's allowance for clerical hire	50.00	
		77.23
Librarian's office		17.65

Publication of Bulletin:			
Printing	$2,086.28		
Engraving	382.32		
Editor's allowance	250.00		
		2,718.60	
Investment:			
Saint Louis, Iron Mountain and Southern Railroad $1,000 bond		979.09	
		$4,772.72	
Balance on hand December 1, 1908		795.83	
			$5,568.55

Respectfully submitted.

Wm. Bullock Clark,
Treasurer.

Baltimore, *December* 6, 1908.

Editor's Report

To the Council of the Geological Society of America:

The Editor takes pleasure in being able to state that, although the Proceedings brochure will not be in readiness for distribution prior to the winter meeting of the Society, the entire text of volume 19 is in type.

As the usual meeting of the Cordilleran Section was omitted, volume 19, both in pages and illustrative matter, is somewhat reduced—indeed, in regard to the former, it but slightly exceeds the average of the first twelve volumes issued by the Society, while in the latter respect it falls short of that average. The average of the first twelve volumes was 577 pages and 43 plates, while the present volume has 617 pages and is illustrated with 41 plates and 31 text figures.

The following tables bring the statistical information down to date:

	Average. Vols. 1–12.	Vol. 13.	Vol. 14.	Vol. 15.	Vol. 16.	Vol. 17.	Vol. 18.	Vol. 19.
	pp. 577. pls. 43.	pp. 583. pls. 58.	pp. 609. pls. 65.	pp. 636. pls. 59.	pp. 636. pls. 94.	pp. 785. pls. 84.	pp. 717. pls. 74.	pp. 617. pls. 41.
Letter-press	$1,575.14	$1,647.12	$1,657.50	$1,661.21	$1,817.03	$2,087.98	$2,015.68	$1,591.32
Illustrations	327.62	477.27	431.21	457.76	706.97	608.68	486.22	289.92
	$1,902.66	$2,124.39	$2,088.71	$2,118.97	$2,524.00	$2,696.66	$2,501.90	$1,881.24
Average per page	$3.30	$3.64	$3.43	$3.33	$3.96	$3.37	$3.42	$3.00

Classification.

Volume.	Areal geology.	Physical geology.	Glacial geology.	Physiographic geology.	Petrographic geology.	Stratigraphic geology.	Paleontologic geology.	Economic geology.	Official matter.	Memorials.	Unclassified.	Total.
	Number of pages.											
1.......	116	137	92	18	83	44	47	.....	60	4	4	593+xii
2.......	56	110	60	111	52	168	47	9	55	1	7	662+xiv
3.......	56	41	44	41	32	158	104	.....	61	15	1	541+xii
4.......	25	134	38	74	52	52	14	.....	47	32	2	458+xii
5.......	138	135	70	54	28	51	107	.....	71	14	9	665+xii
6.......	50	111	75	39	71	99	1	.....	63	25	4	538+x
7.......	38	77	105	53	40	21	123	4	66	28	13	558+x
8.......	34	50	98	5	43	67	58	14	79	8	....	446+x
9.......	2	102	138	.....	44	28	64	16	64	12	....	460+x
10.......	35	33	96	37	59	62	68	28	84	27	17	534+xii
11.......	65	110	21	10	54	31	188	7	71	60	46	651+xii
12.......	199	39	55	53	24	98	5	5	70	2	....	538+xii
13.......	125	17	13	24	28	116	42	4	165	32	29	583+xii
14.......	48	47	48	59	183	118	22	1	80	14	1	609+xii
15	26	124	3	94	36	267	.....	.....	77	17	3	636+x
16.......	64	111	78	30	102	141	19	.....	67	22	15	636+xii
17.......	49	161	41	84	47	294	27	.....	71	9	2	785+xiv
18.......	16	164	141	5	29	246	5	.....	68	40	3	717+xii
19.......	106	108	29	66	30	155	32	.....	56	15	20	617+x

Respectfully submitted.

JOSEPH STANLEY-BROWN,
COLD SPRING HARBOR, N. Y., *December 18, 1908.* *Editor.*

LIBRARIAN'S REPORT

To the Council of the Geological Society of America:

The list of accessions to the library for the year ending November 1, 1908, has been forwarded to the Secretary for incorporation in volume 19 of the Bulletin.

The expenses of this office for the past year are as follows:

To 500 U. P. U. postals and printing of same..............................	$11.00
To clerk hire..	5.00
To postage..	1.25
To express..	.40
	$17.65

Respectfully submitted.

H. P. CUSHING,
CLEVELAND, OHIO, *December 4, 1908.* *Librarian.*

On motion, the report of the Council was laid on the table for one day, according to custom, and G. K. Gilbert and J. E. Wolff were elected a committee to audit the accounts of the Treasurer.

ELECTION OF OFFICERS

President Calvin then announced the result of the balloting for officers for 1909, as canvassed by the Council, and declared the following officers elected:

President:

GROVE K. GILBERT, Washington, D. C.

First Vice-President:

FRANK D. ADAMS, Montreal, Canada.

Second Vice-President:

JOHN M. CLARKE, Albany, New York.

Secretary:

EDMUND OTIS HOVEY, New York city.

Treasurer:

WILLIAM BULLOCK CLARK, Baltimore, Maryland.

Editor:

JOSEPH STANLEY-BROWN, New York city.

Librarian:

H. P. CUSHING, Cleveland, Ohio.

Councilors:

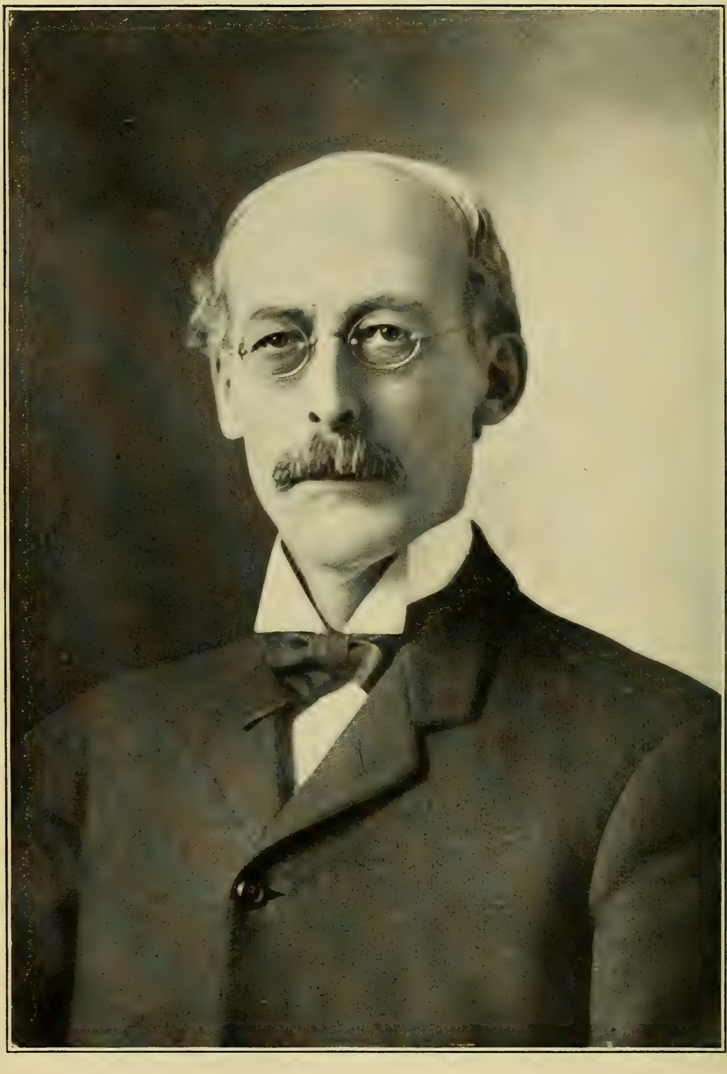
GEORGE OTIS SMITH, Washington, D. C.
HENRY S. WASHINGTON, New York city.

ELECTION OF FELLOWS

The Secretary stated that the candidates for fellowship had been elected by the transmitted ballots. The list is as follows:

ELIOT BLACKWELDER, A. B., Madison, Wisconsin. Assistant Professor of Geology in the University of Wisconsin.

WILLIAM PHIPPS BLAKE, Ph. B., Tucson, Arizona. Director of the School of Mines, Arizona, and Territorial Geologist.



Yours most cordially
Homer T. Fuller

Charles Wilson Brown, Ph. D., A. M., Brown University, Providence, Rhode Island. Assistant Professor and Head of the Department of Geology, Brown University.

Frank Carney, A. B., Granville, Ohio. Professor of Geology, Denison University.

Edward Salisbury Dana, A. B., A. M., Ph. D., 24 Hillhouse avenue, New Haven, Connecticut. Professor of Physics and Curator of the Mineralogical Collection, Yale University.

Cassius Asa Fisher, A. B., A. M., 1832 Baltimore street N. W., Washington, D. C.; U. S. Geological Survey.

Albert Johannsen, B. S., Ph. D., U. S. Geological Survey, Washington, D. C.

Geo. Frederick Kay, M. A., State University of Iowa, Iowa City, Iowa. Professor of Mineralogy, Petrography, and Economic Geology, State University of Iowa.

Henry Landes, A. B., A. M., University Station, Seattle, Washington. Professor of Geology, University of Washington, and State Geologist of Washington.

George Burr Richardson, S. B., S. M., Ph. D., Washington, D. C. Assistant Geologist, U. S. Geological Survey.

Joaquim Candido da Costa Sena, Engenheiro de Minas pela Escola de Minas de Ouro Prato, Brazil. Director of the State School of Mines and Professor of Mineralogy and Geology.

Earle Sloan, Charleston, South Carolina. State Geologist of South Carolina.

George Willis Stose, B. S., U. S. Geological Survey, Washington, D. C. Geologist and Editor of Geologic Maps.

Charles Kephart Swartz, A. B., Ph. D., Baltimore, Maryland. Associate Professor of Geology, Johns Hopkins University.

On call of the President, memorials of the Fellows who had died since the Albuquerque meeting were presented by title as follows:

MEMOIR OF HOMER T. FULLER

BY EDMUND OTIS HOVEY[1]

Dr Homer T. Fuller, son of Sylvanus and Sarah M. (Taylor) Fuller, was born at Lempster, New Hampshire, November 15, 1838, and died at Saranac Lake, New York, August 14, 1908.

He was prepared for college at Kimball Union Academy, and graduated from Dartmouth in 1864 at the head of his class.

After serving three years as principal of the Fredonia (New York) Academy, he spent two years in study at Andover and Union theological seminaries, and then became pastor of the Congregational church at Peshtigo, Wisconsin. He remained there two years, and then returned to the teaching profession as principal of the Saint Johnsbury (Vermont)

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[1] The author desires to acknowledge his indebtedness to Professor B. H. Finkel, of Drury College, for data used in the preparation of this notice.

Academy. In 1882 Doctor Fuller became president of the Worcester (Massachusetts) Polytechnic Institute, remaining there till 1894, when he accepted a call to the presidency of Drury College, Springfield, Missouri. He filled this post most acceptably till age and broken health compelled him to retire from active life in August, 1905. After this he spent his summers at Fredonia and his winters in the south. Early in the summer of 1908 a severe attack of bronchitis left him in a much weakened condition and pulmonary tuberculosis supervened, and after only a few weeks of treatment, when the most sanguine hopes were entertained as to recovery, he was suddenly seized with hemorrhage of the lungs and died on August 14, 1908.

Doctor Fuller was an Original Fellow of our Society, but his published papers on geological topics number only three, and all of them are extremely short. He was a teacher and an administrator rather than an investigator. At Saint Johnsbury he gave instruction in the earth sciences, and at Worcester he had the department of geology and mineralogy, "bringing it up to a high standard and making a fine collection of specimens for illustration as well as laboratory work." At Drury he had little time to devote to science.

On the administrative side, Doctor Fuller's monument is the increased endowment, facilities, enrollment, and general efficiency of the institutions of which he was successively at the head. He bore a high reputation for his work and his accomplishments among the college presidents of the middle west. In 1880 he received the honorary degree of Ph. D. from Dartmouth College; in 1898 the degree of D. D. from Iowa College; in 1905 the degree of LL. D. from Drury on his retiring from the presidency.

BIBLIOGRAPHY

Effects of droughts and winds on alluvial deposits of New England. *Bulletin of the Geological Society of America*, vol. 3, 1892, pp. 148-149.

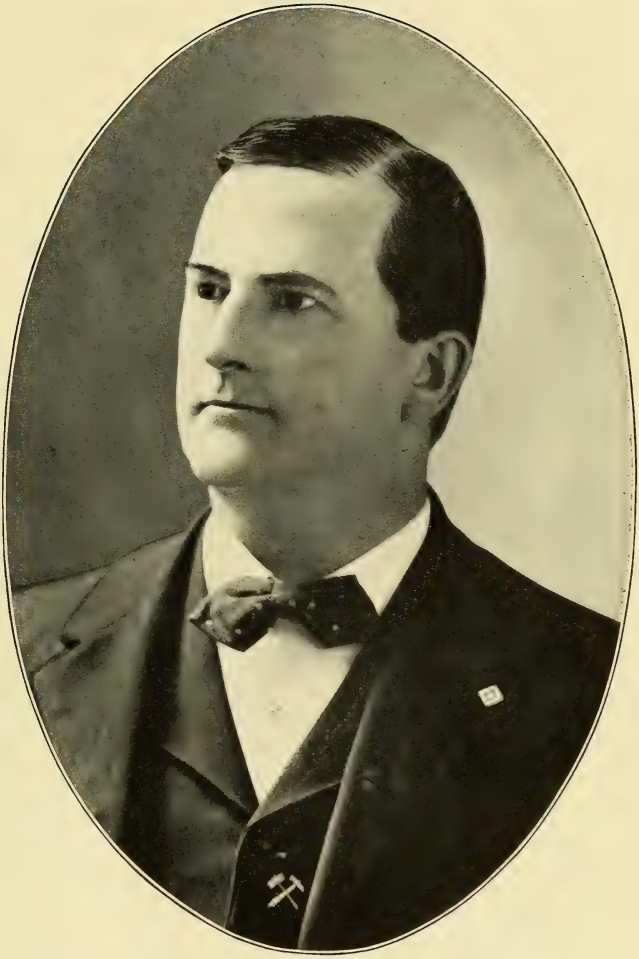
Preservation of glaciated rocks (Massachusetts). (Abstract.) *Proceedings of the American Association for the Advancement of Science*, vol. 39, 1891, p. 246 (½ page).

Corundum and emery. Drury Collection, *Bradley Field Geological Station*, vol. i, 1904, pp. 31-33.

MEMOIR OF W. S. YEATES

BY GEORGE P. MERRILL

William Smith Yeates, State Geologist of Georgia, died at his home in Atlanta on February 19, 1908. Mr Yeates was born in Murfreesboro, North Carolina, December 15, 1856, and graduated at Emory and Henry



I am, sincerely yours,

W. S. Yeates,

State Geologist.

College, Virginia, in 1878, receiving the degree of B. A., and that of M. A. in 1881. Soon after graduation he accepted a position with the United States Fish Commission, and in the winter of 1880-1881 became assistant in mineralogy to Dr George W. Hawes, then recently appointed Curator of Geology in the newly created Department of Geology in the National Museum at Washington. After Doctor Hawes' death, in 1883, Mr Yeates remained in charge of the mineral collections, as Assistant Curator and Acting Curator until May of 1893, when he resigned to assume the position of State Geologist as above noted. During 1884-1893 he also held the position of Professor of Mineralogy and Geology in what was then the Corcoran Scientific School of Columbian (now George Washington) University.

Mr Yeates' position in scientific circles, as may be readily inferred from the above, was that of administrative officer, rather than original investigator. He was, however, an enthusiastic collector of minerals and thoroughly imbued with the museum idea, a quality first developed during his period of service in Washington, and subsequently matured in connection with the State Survey. Indeed, his taste and judgment in the selection of specimens and their installation for exhibition was perhaps his strongest characteristic, and the exhibits illustrating the resources of Georgia, made under his direction at Buffalo, Saint Louis, and other of the great expositions of recent years, were in these respects not excelled and rarely equaled by those of any other state. The Geological Museum now in Atlanta is wholly of his conception and execution and a worthy monument to his aptitude along these lines.

For the reasons above noted, few papers containing the results of original investigations bear Mr Yeates' name. Under his administration a series of preliminary reports have been issued, covering the subjects of building stone, manganese, phosphates, ochres, coal, gold, and other economic deposits, as well as water-power and underground waters of the state.

Mr Yeates was married in 1884 to Julia Ward Moore, of North Carolina, who, with two sons, survives him. He was a member, in addition to the Geological Society of America, of the American Association for the Advancement of Science, the American Institute of Mining Engineers, and the Philosophical and Geological societies of Washington.

After presentation of the memorials of the deceased Fellows the regular program of papers was taken up as follows:

The first paper read was

SOME DISTINCTIONS BETWEEN MARINE AND TERRESTRIAL CONGLOMERATES

BY JOSEPH BARRELL

[*Abstract*]

The problem was approached by studying the effects of shore, as compared with subaerial, activities upon the production, transportation, and deposition of gravel. It was determined that the truly terrestrial forces produce vastly more gravel, spread it far more widely, and provide more opportunities for deposition than do the forces of the littoral zone. Conglomerate formations, therefore, should be dominantly of terrestrial origin. In order to determine, however, the mode of origin of particular examples, definite criteria must be drawn between the two classes. It was shown that the thickness was one of the most important of these, marine conglomerates, except under local and special circumstances, being limited to considerably less than 100 feet in thickness, terrestrial conglomerates, on the other hand, being frequently measured in hundreds and occasionally in thousands of feet.

Attention was next turned to the significance of the intercalated non-conglomeratic beds and the relations to the under- and over-lying formations, with the conclusion that the characteristics of the associated strata are frequently of high supplemental value for determining the mode of origin.

Applications of the conclusions were made to several conglomeratic formations.

Professor Barrell's paper was discussed by G. K. Gilbert, J. Barrell, and W. H. Hobbs.

REPORT OF COMMITTEE ON GEOLOGIC NOMENCLATURE

Arthur Keith reported that the Committee on Geologic Nomenclature had organized, with T. C. Chamberlin as chairman and Arthur Keith as secretary.

The committee is constituted as follows:

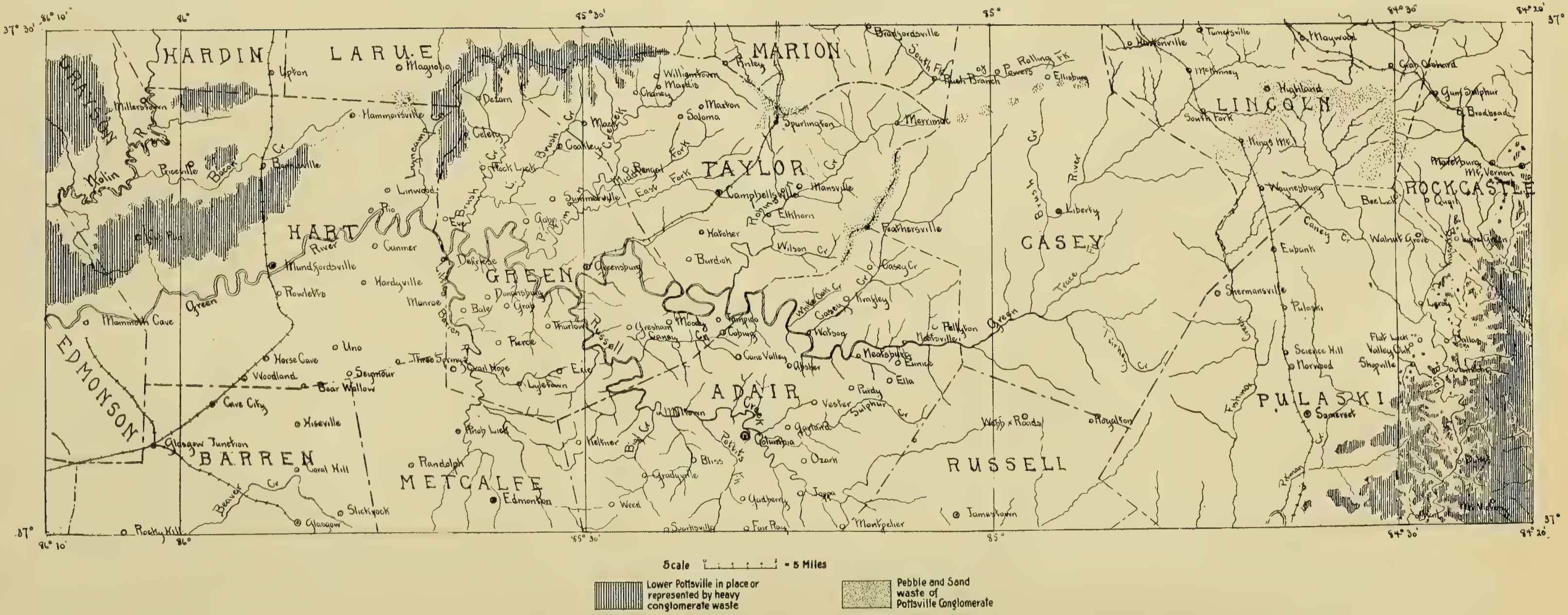
For the Geological Society of America: T. C. Chamberlin and W. B. Scott.
For the U. S. Geological Survey: Arthur Keith and David White.
For the Association of State Geologists: J. M. Clarke and E. A. Smith.
For Canada—Geological Survey: F. D. Adams. Other official surveys: W. G. Miller.
For Mexico: J. G. Aguilera.

The following papers were read by title:

FIRST CALCAREOUS FOSSILS AND THE EVOLUTION OF THE LIMESTONES

BY REGINALD A. DALY

This paper has been published as pages 153-170 of this volume.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86° 10'
86°
85° 30'
85°
84° 30'
84° 20'
37°
GRAYSON
HARDIN
LARUE
MARION
TAYLOR
LINCOLN
ROCKCASTLE
HART
GREEN
CASEY
PULASKI
ADAIR
RUSSELL
METCALFE
BARREN
EDMONSON
Upton
Magnolia
Millerstown
Hammonsville
Munfordsville
Rowletts
Mammoth Cave
Horse Cave
Woodland
Cave City
Glasgow Junction
Glasgow
Rocky Hill
Bear Wallow
Three Springs
Greensburg
Campbellsville
Columbia
Edmonton
Liberty
Somerset
Mt. Vernon
Jamestown
Green River
Scale = 5 Miles
Lower Pottsville in place or represented by heavy conglomerate waste
Pebble and Sand waste of Pottsville Conglomerate

MAP SHOWING REMNANTS OF FORMER CONNECTION BETWEEN EASTERN AND WESTERN KENTUCKY COAL FIELDS

PRIMARY ORIGIN OF THE FOLIATED STRUCTURE OF THE LAURENTIAN GNEISSES

BY FRANK D. ADAMS AND ALFRED E. BARLOW

RELATIONS OF PRESENT PROFILES AND GEOLOGIC STRUCTURE IN THE DESERT RANGES

BY CHARLES R. KEYES

DEFLATION AND THE RELATIVE EFFICIENCIES OF EROSIVE PROCESSES UNDER CONDITIONS OF ARIDITY

BY CHARLES R. KEYES

Then was read

UNCONFORMITY SEPARATING THE COAL-BEARING ROCKS IN THE RATON FIELD, NEW MEXICO

BY WILLIS THOMAS LEE

This paper has been published as pages 357-368 of this volume.

The next paper read was

EVIDENCE OF FORMER CONNECTION BETWEEN THE EASTERN AND WESTERN COAL FIELDS ACROSS CENTRAL KENTUCKY

BY ARTHUR M. MILLER*

[*Abstract*]

It has been a view entertained by a number of students of Kentucky geology that the absence from the highest crest of the Cincinnati anticline of later than Ordovician up to and including the Lower Coal Measure rocks is due in the main to their removal by denudation rather than to lack of deposition.

This was the opinion of Professor Shaler, who recurred to this subject again and again in the publications of the Kentucky Geological Survey while he was State Geologist, and later referred to it in his article "The origin and nature of soils," published in the Twelfth Annual Report of the U. S. Geological Survey. In this view he was supported by W. M. Linney, W. T. Knott, and others on the Shaler and Procter Kentucky state surveys. The evidence which led to such conclusions was the presence of the waste and outliers of the newer formations far outside of their present continuous outer boundaries, and the absence of any materials in these formations which can be recognized as having been derived from older formations exposed on the crest of a "Cincinnati anticlinal island."

A résumé of this evidence and a discussion of its bearings was given by the writer in an article entitled "The hypothesis of a Cincinnati Silurian island," published in the American Geologist, vol. xxii, 1898, pages 78-85.

Citations giving Professor Shaler's views[1] are as follows:

> "The Carboniferous conglomerate . . . increases in thickness as we recede from the Cincinnati axis. It contains a great quantity of pebbles, both in the east and in the west, but not a trace has yet been found of any pebbles which could be attributed to the Cincinnati axis."

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* Manuscript received by the Secretary of the Society December 31, 1908.

[1] Report of Progress, Geological Survey of Kentucky, 1877, p. 17.

In the same report and on same page, referring to the near approach of the two fields in southern Kentucky, and the slight thickness of presumably worn away strata (150 feet) that would have to be restored in order to unite the two fields, he says:

> "It is impossible to resist the conviction that a million of years ago, or thereabouts, this section still contained a continuous sheet of coal reaching from Wayne and Clinton counties, on the east, across to Edmonson and Hart, on the west.
>
> "I believe that the uppermost level of caves which remain open in this region were formed during the time when the hills of this section were so continuously capped with the remains of the coal fields that there could have been no doubt as to the continuity of the two fields—the eastern, or Appalachian, and the western, or Illinois, field. This original continuity being granted, the most material question as to the relations of the two coal fields is substantially disposed of. Going north or south of this line, more and more time for the erosion becomes necessary, for that erosion increases progressively, until at Nashville or Cincinnati we require a duration which is probably somewhere between four and eight million of years for the completion of the down cutting from the true coal measures."

Under "Scientific problems," page 43 of the same report, occurs this statement:

> "Perhaps the most valuable result of the year's work, in a scientific way, is found in the facts that have been gathered, going to show the former existence of a complete union between the eastern and western coal fields across the region occupied by the upper waters of the Green and Cumberland rivers. A treatise on this subject will be found in the Memoirs of the Survey." [This treatise seems never to have been published.]
>
> "I will here only note that the gap between these fields, now only about sixty miles in breadth, is occupied by the waste of the old Coal Measure rocks that cap nearly every high hill. The pebbles of the conglomerate, which are peculiar in their nature and easily recognized, are found on every high point in this district; and in many places the fossil plants of the coal-bearing rocks have been found, showing quite incontestably the former existence of the beds whence they were derived over this area. Less distinct but very suggestive evidence has been found, leading us to raise the question whether the Coal Measures did not cross over the district near Lexington, bringing measures of that age into contact with rocks of a much earlier age."

In his article, "The origin and nature of soils,"[2] occur the following interesting suggestions concerning soil inheritance:

> "As soil descends with the wearing away of its materials, it of course is subjected to a constant change in its mineral character. Thus while soil of the district now occupied by the rich limestone territory of central Kentucky lay upon the Millstone grit it was doubtless of a sandy and rather sterile nature; when in its descent it came into the limestone bed it must have been fertile; still further down, encountering the Devonian or Ohio shale, which because of its mineral character is rather unfit for plants, the soil would again have been reduced to a sterile state. Finally, in downward migration the surface entered the rich fossiliferous beds of Silurian age, and from the storehouses of the ancient marine life it acquired the exceedingly nutritious character of the so-called blue grass soil.
>
> "As soil migrates downward, the greater part of the debris which it inherits from the rock through which it passes is dissolved and goes away to the sea. There are, however, certain materials which may remain for a long time in the soil because they are peculiarly insoluble. Thus in the limestone soils of Kentucky, the greater part of which are derived from the rocks on which they now lie, we often find many flinty and cherty bits which came into the layer when it was in a geological position a thousand feet or more above the site now occupied by the soil."

The elaboration of this idea in Shaler's "History of Kentucky," in which he coins the happy expression "geological distribution of politics," and comments on how the distribution might have been affected by differing rates of denudation, has been enjoyed by every student of Kentucky history.

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[2] Twelfth Annual Report of the U. S. Geological Survey, pp. 302-303.

Linney's contribution to the subject is seen in his report on Lincoln county under the head "Waste beds," on page 26:

> "Over every portion of Lincoln county are to be seen the waste of beds which were once in position over those now seen in place. Corals and chert from the Corniferous are very common. These and the geodes from the Carboniferous are hauled off from many fields and used for repairing roads. Blocks of sandstone and masses of conglomerate are not infrequent over the blue limestone beds.
>
> "Over the Subcarboniferous part of the county the remains of the Saint Louis beds are seen nearly everywhere; and over these are spread, sometimes many feet in depth, the sands and pebbles of the base of the Coal Measures. There can be no reasonable doubt that all the series of rocks now seen in the county were once continuous over its surface, unless we except some of the thin beds of the Upper Silurian, and that on top of these were the Subcarboniferous limestones and the lower portion and perhaps all the Coal Measures."

W. T. Knott, in his report on Marion county, refers to the tops of the knobs in that county still carrying the "waste of the conglomerate, in some places consisting of quartz pebbles, well worn and masses still compacted."

The work of the present geological survey has been confirmatory of the views on this subject entertained by the workers on the Shaler and Procter surveys.

Excavations in the city of Lexington and barite mining operations in the blue-grass region have brought to light Waverly geodes, which can not well be accounted for on any other hypothesis than that the beds containing them formerly went over the "Jessamine dome" of the Cincinnati anticline.

The work of the writer during the past summer in the counties of Green, Taylor, and Adair has supplied additional proof, if such were needed, that the Coal Measures once extended across the Cincinnati anticline. The remnants still remain on the highlands that mark the dividing of the waters between the Salt and Green rivers. They exist like stepping-stones between the two coal fields.

Professor Foerste had noted and mapped a tongue of conglomerate extending out from the Western coal field between the Green river and Bacon creek of Nolin river for some distance east of the Louisville and Nashville railroad.

He did not trace it farther than 3 or 4 miles east of the railroad. A number of years ago the writer had noticed a belt of conglomerate waste crossing the old Bardston and Nashville turnpike south of Magnolia, and during the past summer found a continuous belt of it, forming the highland along the boundary of Green-Hart, Green-Larue, Taylor-Larue, and Taylor-Marion counties. This conglomerate is much disintegrated; still it is a very heavy deposit, estimated to be 50 feet thick, and much of it is practically in place. The pebbles of it are remarkably large, many of them being as large as hens' eggs, whereas the usual size for the conglomerate pebbles in Kentucky is that of pigeon eggs, or even as small as large peas (hailstone-grit). Where in place, or nearly in place, it rests on Saint Louis limestone, which is also generally badly disintegrated and indicated mainly by abundance of chert, a conspicuous element of which is silicified *Lithostrotion canadense* and *L. proliferum*. There is no sign of the Kaskaskia (Chester) in this region, though immediately south of the Green river the knobs are capped by Kaskaskia, with no sign of the waste of the conglomerate overlying it. Such a knob is Maxey, a mile west of the village of Defriese, in Hart county. There is also a knob on the north side of the river near Rio, in the same county, which is capped by Kaskaskia.

There is every evidence that the erosion interval antecedent to the deposition of the conglomerate was greater here than in most other places. Though now occupying a watershed, the remnants of the conglomerate seem to be parts of a continuous belt of channel deposit which had a transverse course across what is now a saddle in the Cincinnati anticline. In its channel deposits aspects it resembles the conglomerate of the Rockcastle river and Roundstone Creek drainage of the Eastern coal field, as described by M. R. Campbell in his "Report on the geology of the London quadrangle."

Underneath the conglomerate, on the boundary between Green and Larue counties, there is an iron ore (limonite) which was formerly smelted in that region. It has the same geological position and appearance as the Red River iron ore of the Eastern field.

The topography of the country is also very similar. Narrow comblike ridges lead away from the main dividing ridge, which is here a part of "Muldrows hill." The culture features are also similar. To one traversing this region along the ridge roads winding through forests of chestnut and oak timber, with here and there a one- or two-room log cabin, surrounded by a small clearing, it is hard to divest oneself of the idea that he is in the Eastern Kentucky coal field. With such similarity in natural surroundings one is not surprised to learn that now and then a wild turkey is seen, that wildcats are not unknown, feuds not uncommon, and that the moonshiner is not entirely extinct.

Eastward from this point, along the boundary between Taylor and Marion, and across Casey county to the headwaters of Green river, in Lincoln county, the remnants of the conglomerate along the crest of Muldrows hill become more discontinuous and are represented by thinner and more disintegrated Southward flowing streams in Taylor county have distributed this waste o wide areas, and there are few places as far south as the latitude of Campbe ville where a search for conglomerate pebbles in the soil will not reveal th presence. There is a rather remarkable belt of pebble waste along the dividing ridge between Casey and Robinson creeks on the boundary between Casey and Taylor and Adair and Taylor. The presence of these patches of waste is indicated by dots on the map. Lack of accurate mapping of Casey makes it impossible to indicate the position of these in that county with precision, but the pebbles and masses of conglomerate are known to occur on the tops of all the high knobs into which Muldrows hill breaks up as it approaches the head of Green river.

Beyond the Green river we know that the high lands are covered with this waste. Linney refers to it in his "Report on Lincoln county," and the writer can confirm this so far as the top of Kings mountain is concerned. This carries us to the confines of Rockcastle county, where the outliers of the Eastern Coal Measures set in, at first non-conglomeritic, but as the vicinity of Roundstone creek and Rockcastle river is approached the lower measures become more pebbly, and massive conglomerate cliffs are the conspicuous features of the landscape.

It seems, therefore, that the facts here presented warrant the inference that a continuous belt of Lower Coal Measures formerly extended across southern Kentucky from the Appalachian to the central fields.

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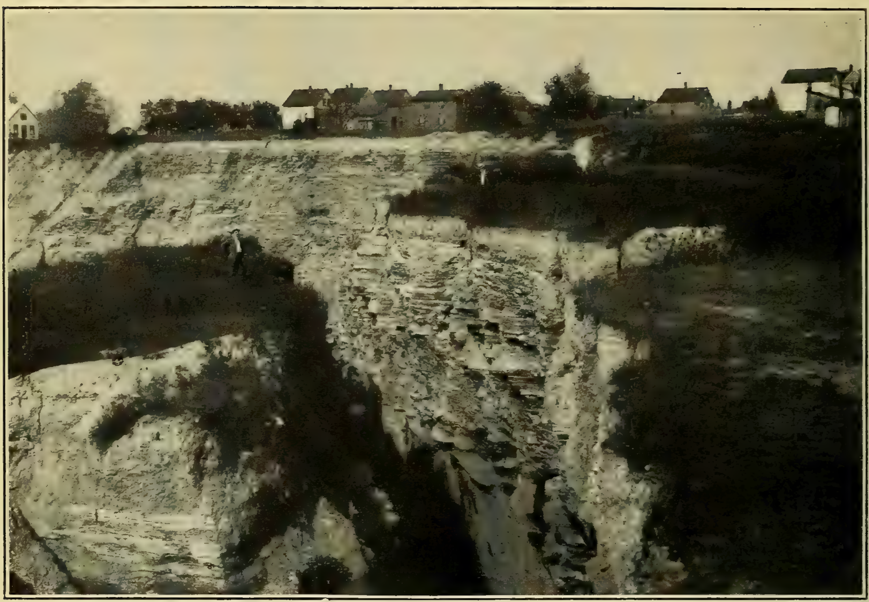

FIGURE 1.—THE FISSURE FROM THE TOP OF THE CLIFF

This view shows the succession of the rocks and the amount of displacement, which is slightly more than the height of the man standing on the sunken block at the left; the amphitheater which formed one wall of the rounded point is also shown in the distance. Photograph by Frank Carney.

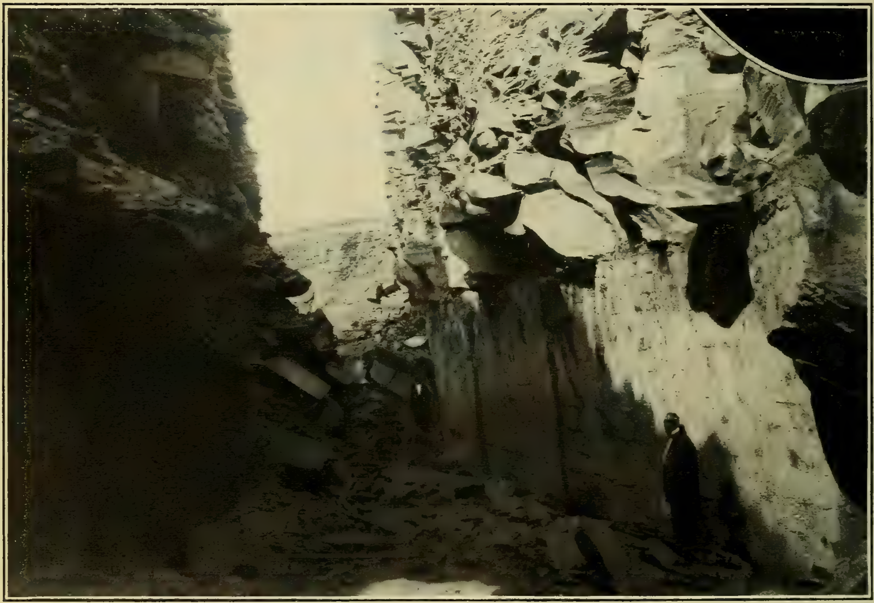

FIGURE 2.—VIEW OF THE FISSURE ABOUT FORTY FEET BELOW THE SURFACE

The contact of Cleveland and Chagrin shales is shown immediately above the large weathered joint plane in the Chagrin; the dimensions of this plane are 95 by 14 feet, as far as could be measured; it is believed that this surface largely influenced the position of the crack. Photograph by Frank Carney.

LANDSLIDE IN SHALES AT CLEVELAND, OHIO

Then was read

BEARING OF THE TERTIARY MOUNTAIN BELT UPON THE ORIGIN OF THE EARTH'S PLAN

BY FRANK BURSLEY TAYLOR

This paper will appear in volume 21. It was discussed by H. F. Reid, B. K. Emerson, J. Barrell, W. H. Hobbs, A. P. Coleman, and F. B. Taylor.

The session adjourned at 12.30 P. M.

The Society convened again at 2.10 P. M. in two sections. The first paper read in the main section, under the chairmanship of President Calvin, was

ON FAULTS

BY HARRY FIELDING REID

This paper has been published as pages 171-196 of this volume.

This was followed by

MASS MOVEMENTS IN TECTONIC EARTHQUAKES

BY HARRY FIELDING REID

These two papers were discussed by W. H. Hobbs and H. F. Reid.

The next paper was read by title

ALASKAN EARTHQUAKE OF 1899

BY LAWRENCE MARTIN*

The Society then listened to the oral presentation of the paper:

LANDSLIDE ACCOMPANIED BY BUCKLING, AND ITS RELATION TO LOCAL ANTICLINAL FOLDS[1]

BY FRANK R. VAN HORN

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* Introduced by C. K. Leith.

[1] Manuscript received by the Secretary of the Society October 21, 1909.

Introduction

The landslide in question occurred at the shale brick plant of the Cleveland Brick and Clay Company, situated in Mill Creek valley, in the portion of Cleveland, Ohio, called Newburg. The writer is indebted for much information to the officers of the brick company.

Geology of the Region

The company mentioned above obtains its shale from the cliff which forms the southeast valley wall of Mill creek. This cliff is 112 feet high, and at the surface consists of about 3 feet of glacial drift. This is followed by 2 to 3 feet of blue shale, which probably belongs to the Bedford of the Lower Carboniferous. This blue Bedford is succeeded by 18 to 20 feet of Cleveland, which is divided into 3 layers. The uppermost is a dense black shale, followed by a layer of blue shale, while the bottom layer is a massive black shale. The black shales are highly bituminous. The Cleveland belongs to the uppermost Devonian, and is underlain by about 88 feet of Chagrin (formerly called Erie) shale, which has a blue color, and is more thinly bedded than the Cleveland. The Chagrin is also Upper Devonian, and contains 2 or 3 sandstone layers, having a maximum thickness of about 10 to 15 inches.

Both Cleveland and Chagrin shales are jointed with greater or less regularity, although with one exception the surfaces are not large. The Cleveland shows the jointing better than the Chagrin and breaks up into rectangular blocks. Nevertheless, the largest joint plane of all was noticed in the Chagrin, where it formed the wall of the fissure, to be described later. This surface was found to be 95 feet long and 14 feet high, as far as it was exposed to view. It probably extended farther, but was obscured by fallen debris. (That this assumption was correct is proven by a photograph taken at a later date and shown in plate 106.)

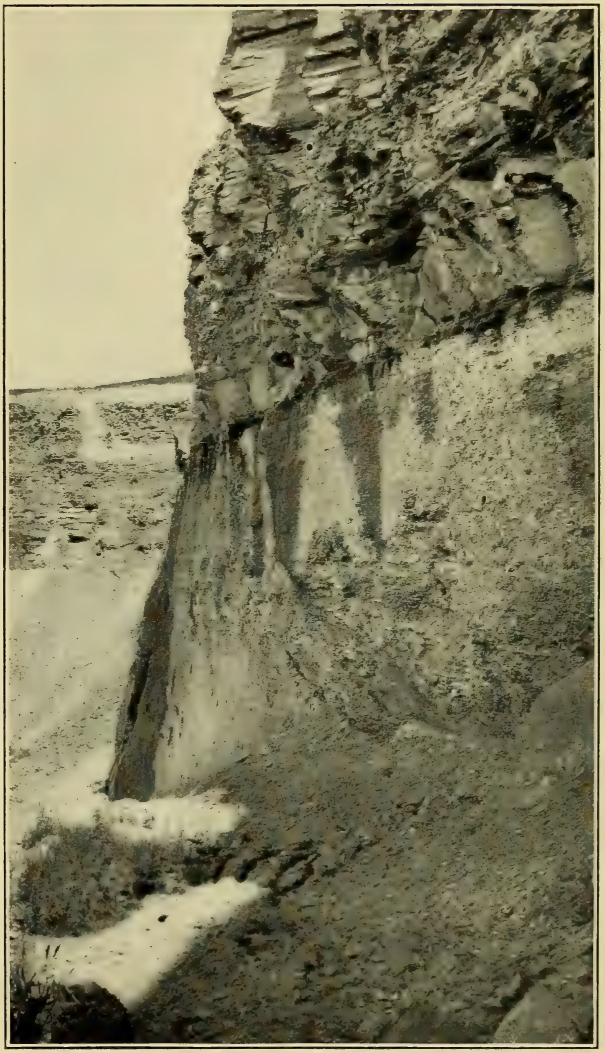
The Landslide

OCCURRENCE

During the past six years the brick company has been excavating the cliff at the rate of about 60,000 to 75,000 tons a year, and has made an amphitheater with vertical walls immediately in the rear of the plant. As the concave west wall of this excavation curves into the valley, it is cut into on its opposite side by Mill creek. Thus the operations of the brick company on one hand and the stream on the other have carved the valley wall into a rounded point made by two concave curves. This rounded point was the scene of the landslip, which may be regarded as having three different stages, as follows: the formation of the crack, the buckling, and the settling.

FORMATION OF THE CRACK

The beginning of the fissure was first observed on Monday, August 17, 1908, at 3 P. M., when a workman who was drilling for a blast near the top of the cliff in the Cleveland layers reported a crack 3 inches wide. The next morning (Tuesday), at 4 o'clock, the cleft had attained a maximum width of 7 feet, and continued to open until Wednesday, when it reached its widest dimensions, which varied from 17 to 22 feet (see plate 105, figures 1 and 2). The crack



LATER VIEW OF THE SCENE OF CLEVELAND SLIDE

This view is from near the same place as figure 2, plate 105, but was taken one year after the occurrence of the slide. It shows the joint plane was about 100 feet long and 80 feet high, and undoubtedly caused the position of the crack. Photograph by Frank R, Van Horn.

was about 250 feet long, and ran in a northeast and southwest direction for about 100 feet, after which it turned nearly west for the remainder of the distance. The fissure was about 30 to 40 feet deep, as far as could be observed, and was filled up to that depth with loose joint blocks and debris which had fallen from the walls. The crack followed almost entirely weathered joint planes, which were stained with limonite from the decomposition of pyrite and marcasite contained by these shales in variable amounts. It was in the wall of the fissure on the cliff side that the large joint plane in the Chagrin mentioned previously was observed. It was evidently this surface which gave direction to the fissure for the first 100 feet of its course (see plate 106). The block broken off by this crack resembled an elliptical cone truncated at the top. The upper surface of this conical mass was approximately 250 feet long and 30 feet wide. Around the base on the valley floor it measured, roughly, 300 feet and was 112 feet high. Mr H. D. Pallister kindly attempted to compute its dimensions, which was difficult because of lack of knowledge of its internal outline. He used 3,200 pounds for the weight of a cubic yard of drift and 4,533 pounds for the Bedford and Cleveland, while 4,766 pounds was used for a cubic yard of Chagrin. By this method it was found that there were 18,521 cubic yards, weighing 43,530 tons. Since this seemed rather small, the writer calculated its contents as a solid bounded by rectangles in order that an idea of the maximum contents might be reached, and found that the block would contain 37,330 cubic yards and weigh 87,732 tons. Since the slide has furnished the brick company with shale for over 15 months, it is evident that the larger estimate is more nearly correct.

BUCKLING

The buckling, which is the most interesting feature of the landslide, was first noticed on Tuesday afternoon, August 18, about 24 hours after the first appearance of the crack (see plate 107). The axis of this anticlinal fold was traceable for about 200 feet in the shale at the base of the cliff, following around the head of the rounded point, until it finally became lost in the fragments which had fallen down from above as a result of the dislocation. The maximum height of the anticline was about 4 to 5 feet, while the greatest width attained was 8 to 10 feet. The buckle reached its greatest height about a week after the development of the fissure, but has continued steadily for over a year, although the rate of elevation has constantly decreased. The extent of the motion may be gathered from the amount of work which has been required for the excavation of the brick company's sewer, which was crushed by the buckling. This sewer runs along near the foot of the displaced block about 7 feet below the valley floor. It required 34 days for 2 teams and 7 men to excavate the debris in the sewer trench, which has since been entirely filled again by the buckling movement. Since the axis of the anticline lies between the grinding pans and the shale bank, the ground is kept shoveled off as fast as it arches up, and the buckle was not allowed to attain any size except toward the southwest end of the slide.

SETTLING

The officials of the brick company maintain that the buckling started first, and that no settling was perceptible until about 2 days after the formation of the fissure, while buckling was observed 24 hours afterward. The sinking was observed by means of a horizontal board placed across the cleft at the top of the cliff. At the time the writer first saw the slide, about two weeks from its inception, there was a throw or vertical displacement of about 6 feet. This downward movement continued until December 22, when the displacement was about 20 feet. On February 22, 1909, the brick company officials informed the author that where they are excavating at the base of the cliff near the northeastern extremity of the crack they are uncovering shale layers for a distance of more than 30 feet, which dip toward the valley. This would seem to indicate that the layers of rock at the base of the whole mass have settled downward into the valley floor.

Classification of the Dislocation

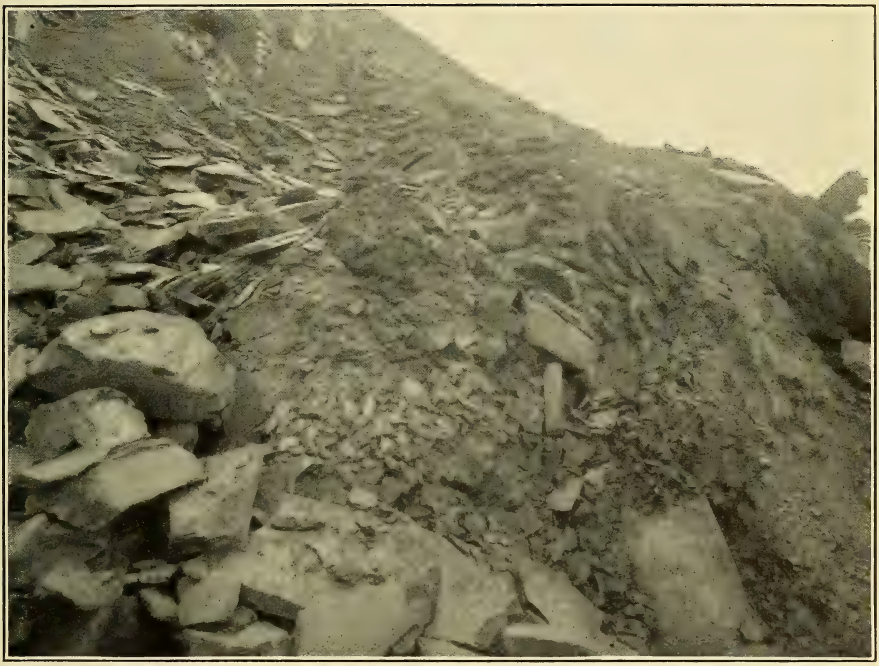
This movement of the rocks has been classified as a landslide, although it might be called a fault, since it has been shown that the dislocated mass had a throw of 20 feet. This slide, however, differs from the usual landslips in respect to the slowness with which most of the attendant phenomena took place. The formation of the fissure was the most rapid, and covered a period of two days, while the buckling and settling have extended over a period of several months. The amount of lateral motion was also very small in this slide, which belongs to the more uncommon type of "rock slides" rather than to the "waste slides" of loose material, which are so common in the springtime and during wet seasons along valley sides. Another point of difference is that the saturation of the ground with percolating water is a very important cause of most landslides, while this one occurred during the dryest summer that Cleveland has experienced for ten years.

Causes of the Fracture and attendant Phenomena

It is possible to consider the causes of this landslip and its accompanying features from two different standpoints as follows: either the landslide caused the buckling, or the latter was the cause of the former. The writer can see no very important reason for the second assumption, which requires that the shales of the valley floor should first give way and arch up, thereby causing the cliff wall to sink down into the place vacated by the shale. On the other hand, there are several reasons for the first hypothesis, and it is accordingly proposed to consider that the buckling was caused by the landslide.

No mass under the action of gravity can move with a pure horizontal motion unless it is sliding in an inclined plane. On the other hand, a tilting or tipping motion can be produced by a yielding of the foundations. Settling of the dislocated portion of this slide is quite conclusive proof that the foundations were weak, and there are several factors which may have contributed to the weakening of the shales at the base of the cliff.

One possible cause of weakening is the action of underground water in former seasons moving along the joint and bedding planes. It has been previously shown that these shales were much jointed in their normal condition, and that the surfaces of these joint planes were all weathered. This action must have been performed by water percolating from the surface downward through the joint planes. This water continues its journey downward, and will finally work its way along the bedding planes until it reaches the stream



ANTICLINE PRODUCED BY BUCKLING OF THE SHALES AT THE BASE OF THE LANDSLIDE AT CLEVELAND, OHIO

The hat is placed on the axis of the flexure, which at this point is unsymmetrical; the view was taken nearly three weeks after the occurrence of the slide, so that the fold which has been dug away up to this point has been more or less disturbed by the workmen. Photograph by Frank Carney.

in the valley. Some of the shales are more thickly bedded, and would not allow seepage like the thinly bedded portions such as the Chagrin, which occurs at the base of the cliff. In this Chagrin are also found several sandstone layers, which would permit much easier circulation than the shales. Along its course it will perform the usual work of underground water and dissolve any soluble material, such as the iron sulfate formed by the decomposition of the pyrite and marcasite, which are always present in these shales in variable quantities. The breaking up of these substances may also cause the formation of free sulfuric acid, which in turn would attack the aluminum silicate of the shales, and form alums. This chemical action would, therefore, result in the weakening of those shale layers along which water could circulate.

Another cause which probably aided in weakening the foundations of the cliff is that up to 6 years ago the stream flowed within 25 feet of the base of the displaced block. The course of the creek was changed at the time the brick plant was erected in order to make their shale bank more accessible. The river in previous times flowing so near the base of the point would undoubtedly have exerted some mechanical and chemical action on the shales. This old waterway, although filled up, would serve as a better drainage channel than if it were solid shale.

Still another factor which might aid in rock disintegration at this point is the fact that at the time the creek was changed a sewer was built along the front of the cliff about 7 feet below the kiln floor and nearer the cliff than the former stream course. This excavation was filled up with loose material, which would make a channel of porous character along which water could circulate with ease and exert more or less destructive effect on the shale foundations of the cliff. This waterway would give the waters coming downward through the joint planes of the bank a quicker circulation, and thereby enable them to perform their work of chemical disintegration at a faster rate.

The normal weathering action of rain and frost would be expected to exert some effect on the shales, and this action would be greatest on the outside of the cliff, and probably more prominent at the bottom of the same, where the amount of water would be greater. It is to be noted that the axis of the flexure runs along in front of the face of the cliff, where the shales have been longest exposed to the weather and other disintegrating agents.

Blasting of the shale in the amphitheater to the northeast of the slide occurs quite frequently, and it seems possible that the continued concussions might even fracture the adjacent shales. It certainly would tend to loosen the joint blocks of any rocks in the immediate vicinity.

It seems plausible that any one, but more probably all of these factors combined, may have weakened the shale layers at the bottom of the cliff to such an extent that the simple weight of the mass would tend to cause the outward face to settle on its base. The direct cause of the sinking might well be the dynamite blasts. As a result of the settling, tension would be produced in the strata for some distance into the valley wall. This would ultimately result in the formation of a crack and the separation of the point from the rest of the bank. In this case it was comparatively easy for the rupture to form on account of the weathered joint planes, especially the large one in the Chagrin formation, which measured 95 feet long and 14 feet high and must have exerted considerable influence on the position of the fissure. Immediately following the formation of the crevice, the block would be resting on a plane slightly inclined toward the valley. The weight of the mass now has a horizontal component in addition to the previous vertical one, which produces motion away from the cliff as well as slightly downward. This might produce sufficient pressure to cause buckling at the base of the block in the valley floor, where the shales are presumably weaker from longer exposure to erosive agents. In this instance it would seem that the vertical component was the more important factor in forming the fold, since there seems to be but little lateral displacement. Professor Charles A. Cadwell has pointed out to the writer the resemblance of this slide to buildings with weak foundations, and believes that the flexure was caused principally by the fact that the center of gravity of the sunken portion is vertically not above the center of the supporting base, but rather nearer the valley side. This causes the unit pressure on the valley side of the base to be enormously greater than on the bank side. In testing the supporting power of foundations for proposed buildings, and especially for dams, it is common engineering experience that at so-called "failure" the ground will rise up around the imposed load, flowing out from beneath it, as was reported to be the case with the test loads applied on the site of the State house at Albany, New York. It is also known that clay-like rocks, especially in coal, but also in other mines, sometimes are inclined to "squeeze" at comparatively shallow depths below the surface. The buckling of large timbers in the Michigan iron mines is also quite a common occurrence. It may be objected that such materials are far weaker than shales, and that the latter would require much greater pressures to flex them than those involved in this landslide. However, since these shales have actually buckled, the writer sees no other explanation for the fact than the vertical and to some extent the lateral pressures inherent to the dislocated mass.

The settling of the mass was not noticed until some time after the buckling, which would indicate that the sinking was caused by the buckling, and again shows the resemblance of this movement of rock to the behavior of building foundations at "failure" where the vertical pressure is the chief factor.

Relation to Anticlines along Stream Valleys

Professor H. P. Cushing mentioned to the author the fact that in several instances around Cleveland and elsewhere he had encountered anticlines of local nature in postglacial gorges. One explanation of such flexures has been that they were caused by the vertical pressure of the walls on the valley floor, which relieves the pressure by buckling. It is thought, however, that many of these folds occur where the walls of the valley are not thick enough to produce such a pressure as would seem necessary. With this Cleveland landslide as an object lesson, the writer has come to the conclusion that elsewhere anticlines of local character, especially in shales, may have been produced by landslides similar to the one which is the subject of this paper.

Other Landslides of similar Nature

During the discussion of the above paper at the Baltimore meeting Doctor J. W. Spencer[2] called attention to a landslide which took place April 15, 1884, on the Grand river, about 2 miles southeast of Brantford, Ontario. The bank was 90 feet high, and at the top was composed of 20 feet of thinly bedded sandy Saugeen clay, while the remainder consisted of Erie clay, which was also finely stratified. "Owing to the forward movement and reaction, the deposits of the Erie clay have been raised into perfectly truncated anticlinal folds, which are composed of vertical strata more or less twisted." These "truncated anticlines" were probably due to vertical jointing in a very thick mass with considerable lateral displacement. The behavior of the layers of Erie clay seems similar to that of two blocks of wood of equal length made into a horizontal column which is free to "fail" upwards. A heavy horizontal thrust applied with enough eccentricity to produce failure will make the blocks fly upward at the center and show the end of the grain, and would therefore resemble a truncated anticline. It would seem to the writer that the Brantford slide does not show the same type of thrusting as that of the Cleveland occurrence, which did not have as much lateral translation.

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[2] A landslide at Brantford, Ontario, illustrating the effects of thrusts upon yielding strata. American Naturalist, 1887, p. 267.

Dr G. B. Richardson called my attention to a paper read at the Rochester meeting in 1902 by T. C. Hopkins and Martin Smallwood.[3] However, there was nothing published but an abstract, which read as follows: "A number of unique folds occur in several small and rather deep ravines in the vicinity of Meadville, Pennsylvania. They are limited in extent, both vertical and linear, and so far as known occur only in the bottom of ravines. The relation of the folds to certain landslip terraces suggests a cause for these folds." This abstract seemed to deal with phenomena so similar to the Cleveland landslide that the author wrote to Professor Hopkins to inquire if anything further had been published on the subject, and has just received a copy of the original paper.[4] The rocks are sandy shales belonging to the Cuyahoga stage of the Lower Carboniferous, and there are several folds exposed in four different ravines. In every case where anticlines occur they are found to be in proximity to what Dr G. K. Gilbert calls landslide terraces.[5]

The conclusion of the paper is as follows: "In view of the conditions as described above, the writers conclude that the small folds in the ravines in the vicinity of Meadville are caused partly if not wholly by landslides on the steep hillsides bordering the ravines."

CONCLUSION

The Cleveland landslide, which has been described in this paper, was caused by a weakening of the shale rocks at the base of the cliff by various erosive agents, possibly assisted by blasting. This resulted in a sinking of the outside part of the valley wall, which produced a tension that caused a portion of the cliff to crack off. The dislocated mass then rested on an inclined plane, so that its weight had both vertical and horizontal components, which produced sufficient pressure to cause the shales of the valley floor to buckle and the separated block to settle on its base. In this case the vertical pressure was more important, and was considerably greater on the outer base of the slide, since it was resting on an inclined plane. It is believed that other anticlines of local nature, especially in shales along stream valleys, have been caused by landslides in a manner similar to the one which has been the subject of this paper.

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[3] T. C. Hopkins and Martin Smallwood: Some anticlinal folds. Bulletin of the Geological Society of America, vol. 13, p. 530.

[4] T. C. Hopkins and W. M. Smallwood: Discussion of the origin of some anticlinal folds near Meadville, Pennsylvania. Bulletin of Syracuse University, series IV, number 1, p. 18.

[5] Grove Karl Gilbert: Lake Bonneville. Monograph I, U. S. Geological Survey, p. 83.

This paper was discussed by H. P. Cushing, J. W. Spencer, G. B. Richardson, Frank R. Van Horn, G. K. Gilbert, and G. H. Ashley.

Then was read by title

THE VOLCANO KILAUEA

BY C. H. HITCHCOCK

After this was presented orally

MOUNT PELÉ OF MARTINIQUE AND THE SOUFRIÈRE OF SAINT VINCENT IN MAY AND JUNE, 1908

BY EDMUND OTIS HOVEY

[*Abstract*]

The paper gave the results of an expedition made to the Lesser Antilles in April to July, 1908, illustrating by means of lantern slides the progressive changes in 1902, 1903, and 1908 due to the great eruptions and the efforts of nature and man to recover from them.

A part of the paper is published under the title, "The clearing out of the Wallibu and Rabaka, Saint Vincent, gorges," as pages 417-426 of this volume.

The last paper of the afternoon was presented orally. It was

MULTIPLE GLACIATION IN NEW YORK

BY H. L. FAIRCHILD

[*Abstract*]

Evidence of pre-Wisconsin glaciation in territory surrounding New York State—in Canada, Ohio, Pennsylvania, New Jersey, and New England—implies a similar history for the state.

An accumulating body of facts points to at least two ice invasions. Such features are: (1) the widespread occurrence of more or less difference between the surficial and the deeper till, as shown in color, texture, composition, with sometimes a distinct surface of separation; (2) weathered glaciated surfaces and heavy glacial flutings merely scraped in places by a later abrasion; (3) old planation surfaces which, though protected by Wisconsin till, have lost their glaciated character; (4) probable stream channels not the product of the latest glacial drainage; (5) physiographic features of anomalous relationship.

No interglacial deposits have as yet been found.

This paper was discussed by G. K. Gilbert, R. S. Tarr, F. Carney, A. Penck, and A. P. Brigham.

Adjourned at 5.25 o'clock.

The Society met at 8 o'clock Tuesday evening, in the lecture-room of the geological department, to listen to the presidential address of Professor Samuel Calvin, who chose as his theme "Present phase of the Pleistocene problem in Iowa." This paper has appeared as pages 133-152 of this volume.

At the close of the address the Society and its friends adjourned to the rooms above the lecture-hall and participated in a "smoker" as the guests of the geological department of the university.

SESSION OF WEDNESDAY, DECEMBER 30

Wednesday morning the Society came to order in general session, President Calvin presiding, at 9.35 o'clock.

The Council report was, on motion, taken from the table and adopted.

The Auditing Committee reported finding the Treasurer's accounts correctly cast and properly vouched. The report was adopted.

The Secretary then read a letter from Hon. Gifford Pinchot, chairman of the National Conservation Commission, requesting the appointment of a committee by the Geological Society of America with which the Commission might confer regarding geological subjects. It was voted to empower the President to appoint three Fellows to act as a Committee on Conservation.[1]

Professor Albrecht Penck, of Berlin, who had been invited by the Council to participate in the meeting, presented a paper entitled "Interglacial epochs."

At the close of this paper the special section on correlation withdrew for the continuation of its sessions, and the general section, with President Calvin in the chair, proceeded with the main programme.

The following two papers were read:

GLACIAL WATERS WEST AND SOUTH OF THE ADIRONDACKS

BY H. L. FAIRCHILD

[*Abstract*]

As the lobes of the ice-sheet melted away south of the Adirondacks, high-level waters were held in the Schoharie and Mohawk valleys, into which was

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[1] Later the president (G. K. Gilbert) appointed I. C. White, A. C. Lawson, and E. V. d'Invilliers to serve as this committee.

poured the land and glacial drainage of the time, with consequent elevated deltas. The Schoharie lake had outlets to the Hudson and the Delaware, and subsequently the Mohawk waters overflowed southwestward to the Susquehanna, but finally to the Hudson.

The earliest outlet of the Mohawk Valley waters seems to have been by the col at the head of the Otsego-Susquehanna valley, with elevation somewhat under 1,400 feet. A lower escape was found by the Unadilla valley, at about 1,220 feet, and possibly by the Chenango valley at 1,150 feet. Later the outflow was eastward to the Hudson by Delanson and Altamont and past the face of the Helderberg scarp, at 840 feet as the lowest. The latest flow of the ice-impounded Mohawk waters was south of Amsterdam and past the face of the scarp at Rotterdam.

The copious drainage of the western slopes of the Adirondacks poured into a lake held in the valley of Black river, with the production of a remarkable expanse of sand plains. In the various features and relations which characterize a glacial lake the Black lake is probably the finest example of a glacial lake in the state (though not nearly so remarkable in complexity of drainage and history as the Genesee waters). The earliest outflow of the differentiated waters of the Black valley was southward past Remsen into the Mohawk lake, with delta built at Trenton and Trenton Falls. The second escape was southwestward, at Boonville, into the inferior Mohawk lake, with delta north of Rome. The third stage had westward outflow, curving around the high ground between the Black valley and the Ontario basin, at Copenhagen and Champion, the flood pouring into lake Iroquois at Adams.

CORRELATION OF THE HUDSONIAN AND THE ONTARIAN GLACIER LOBES

BY H. L. FAIRCHILD

[*Abstract*]

In the waning of the Labradorian ice body the Adirondack massif became uncovered, at first as an island, with probable westward flow of the ice through the Mohawk depression. Later the glacial flow was divided into a Champlain-Hudson lobe and a Saint Lawrence-Ontario lobe. For a long time the Hudsonian lobe pushed an ice tongue westward into the lower Mohawk valley, while the Ontarian lobe sent one eastward into the upper Mohawk valley. Imprisoned between the two opposing ice fronts the glacial waters stood at high levels in the Mohawk and Schoharie valleys. As the waning ice margins released successively lower passes to southern drainage the waters fell accordingly.

The delta sand plains on the flanks of the Adirondacks and in the upper Mohawk valley, with their various declining altitudes, show the successive levels of the waters; and these levels were determined by the positions of the ice margins with reference to a few critical cols or passes on the divide.

The two papers were discussed together by A. P. Brigham, H. L. Fairchild, and A. W. Grabau.

The next paper was read by title. It was

PLEISTOCENE FEATURES IN NORTHERN NEW YORK

BY H. L. FAIRCHILD

Then the Society listened to the reading of

PLEISTOCENE GEOLOGY OF THE SOUTHWESTERN SLOPE OF THE ADIRONDACKS

BY WILLIAM J. MILLER[1]

[*Abstract*]

The area discussed in this paper is about 60 miles long and 15 miles wide, and extends from Lowville to Dolgeville, New York. The northern portion of the area is occupied by the Black River valley and the southern portion slopes southward toward the Mohawk river.

Some years ago Professor Chamberlin suggested that tongues of ice flowed around the Adirondacks and met in the Mohawk valley.[2] Observations by the writer along the southwestern Adirondacks have an important bearing upon this question of ice movement in northern New York. In the Black River valley the striæ point from south 25° to 40° east and parallel to the strike of the valley, thus showing the influence of the valley in determining the direction of flow. Southward, on the Little Falls sheet, the striæ point more nearly east and west, and show a direction of flow parallel to the Mohawk valley. It has already been established that the ice current was southwesterly through the Saint Lawrence valley and southerly through the Champlain valley, and also that an ice tongue moved westerly up the lower Mohawk valley to meet an easterly flowing tongue from the upper Mohawk valley. During the height of glaciation the main ice current was southwesterly across the Adirondack region. This is shown by numerous glacial striæ in the midst of the Adirondacks and to the south of the Mohawk valley, as well as by the distribution of erratics from the Adirondacks to the south and southwest of the mountains. Bearing in mind all the facts, the writer is led to the conclusion that when the ice, in its southward movement, struck the Adirondacks, it was divided into two currents flowing around the mountains and meeting in the Mohawk valley; that during maximum glaciation there was a strong southwesterly current, but that border currents continued as undercurrents more or less checked in velocity, and that after the disappearance of the ice-sheet from the central Adirondacks border currents were maintained.

There is no evidence to show that ice erosion did any very deep cutting into the pre-Cambrian rocks, but it was much more effective upon the Palezoic sediments. The writer believes that in the Black River valley we have one of the best examples of ice erosion in northern New York. Black river follows close to the Paleozoic-pre-Cambrian boundary line, and the Paleozoics, having a thickness of nearly 1,500 feet, overlap upon the pre-Cambrians. On the Port

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[1] Introduced by W. B. Clark.

[2] Third Annual Report, U. S. Geological Survey, 1881-2, pp. 360-365.

Leyden quadrangle the Paleozoic rocks are distinctly terraced. The steep front of the lowermost terrace rises from 200 to 300 feet, and immediately faces the river. The basal sediments here are weak sandstones and sandy limestones, while the surface of the terrace (several miles broad) is made up of hard Trenton limestone. Along the western edge of this terrace a second slope (Tug hill) rises over 400 feet within a third of a mile. The base of this slope is made up of the soft Utica shale, while the upper part is made up of the Lorraine sandstone and shale.

The steep fronts of the terraces are certainly young topographic features. which preclude the possibility of their having been formed during the long pre-Glacial period of erosion in this very ancient region. On the other hand, little work of erosion has been done in post-Glacial times, as proved by the fact that Black river has not yet cut its way through the recent deposit filling the valley bottom, and also because striæ and kames near the river level have not been disturbed. There is still the possibility that glacial waters might have developed the terraces, but there is no evidence for any such vigorous water action, especially along the higher part of the limestone terrace, where records would surely be left. Kames and glacial striæ are here left undisturbed. Evidently the lowest sediments were cut back by the ice to develop the steep slope which now faces Black river. As Robert Bell has suggested for certain Canadian occurrences,[3] the exposed edges of the sediments resting on the very hard pre-Cambrians presented the most favorable attitude for ice erosion, and they were stripped off the pre-Cambrians until, as Bell says, "the resisting rock front had attained a height and weight sufficient to counterbalance those of the glacier." In much the same way the steep front of the second terrace was developed by stripping off the soft shales from the hard limestones. The maximum amount of shale thus removed was probably several hundred feet, but not over a wide area. Ice erosion was considerably favored by the fact that the ice moved uphill along the valley, and so had its cutting power increased. Another factor of importance was the angle at which the ice current entered the Black River valley in its sweep around the Adirondacks. The greatest amount of erosion was along the eastern side of Tug hill, and it was just here where the ice must have struck with greatest force as it crowded into the valley.

A remarkable development of glacial sand plains or terraces is to be found within the region here discussed. The greatest sand plain expanse extends from Forestport to an unknown distance north of Lowville, and it has a width of from 5 to 8 miles. This great sand plain has a rather steep front facing Black river, where the deposit is from 200 to 250 feet deep, while it thins out to disappearance eastward. The remarkably concordant altitudes of the plains (from 1,150 to 1,260 feet); their crudely stratified character; the general absence of erratics over the surfaces, and their frequently lobate character all argue conclusively for their origin as delta deposits which were formed in a marginal lake along the waning ice during its retreat from the higher to the lower land along the western Adirondacks. Another fine but smaller sand plain covers about fifty square miles between West Canada and Black creeks (Remsen sheet). A thick bed of clay underlies this sand, and the sand was evidently pushed out as a delta deposit after the deposition of the clay. A number of good examples of smaller sand plains also occur, and all have had a similar origin.

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[3] Bulletin of the Geological Society of America, vol. 1, 1890, p. 296.

Of the glacial lakes the most interesting and extensive one occupied all of the sand flat country from Forestport to north of Lowville. The former presence of this large lake is shown by the great development of unquestioned delta deposits above referred to. These waters were impounded by a waning lobe of ice in the Black River valley. The kames and drift boulders along the western edge of the terraces in the valley show an ice-contact front there. Also the absence of delta deposits on the west side of the river, under Tug hill, shows that the lake did not extend that far west. The failure of any delta deposit to reach out to or across the valley bottom argues for ice occupancy of the deepest part of the valley during the existence of the large lake. The highest water level was apparently something over 1,300 feet (using present elevations) at which time an outlet probably crossed the Black River-West Canada Creek divide near Honnedaga, and flowed southward toward Trenton Falls. Further melting of the ice lobe certainly opened an outlet past Boonville and down Lansing Kill (creek) toward Rome. The pre-Glacial divide was doubtless near Hurlbutville, as shown by the widening of the channel, both northward and southward, from that place; by the existence there of a deep inner gorge; by the aggraded stream bottom north of Hurlbutville; by the fact that the present stream could not have cut the deep, narrow channel there, and by the right elevation of an outlet there. The lake stood at about the 1,250-foot level when it started over this divide, and it cut down the divide rapidly until the 1,140-foot level was reached. By this time the ice had so far melted as to allow an escape of the water northerly and northwesterly along the western side of the ice tongue and into lake Iroquois. Another lower and very distinct lake level was a little below 800 feet, and caused by still further ice retreat to allow an accumulation of water back of a barrier at Carthage. This lake extended southward to Lyons Falls, where it was very narrow. Between Lyons Falls and Carthage the winding stream is now cutting terraces through the old lake deposit. The glacial lake which extended over the sand flat area between West Canada and Black creeks (above mentioned) stood for some time at or near the 1,400-foot level, and during part of the time, at least, may have had an outlet through the Spruce Creek channel.

Many fine kames have been found within the region, their greatest development being in the vicinity of Hinckley (Remsen sheet), where they form kame-morainic ridges with the typical knob and kettle structure. An interesting feature is the occurrence of partially buried kames, which are particularly well shown in the vicinity of Forestport (Remsen sheet). After the formation of the kames and the withdrawal of the ice, the delta sands were built around the kames to partially bury them. In this way many kames were doubtless completely buried, as must have been the case where the sands are so deep in the Port Leyden region.

The paper was discussed by G. K. Gilbert and Albrecht Penck.

Then was read

WEATHERING AND EROSION AS TIME MEASURES

BY FRANK LEVERETT

[*Abstract*]

The paper set forth the use that may be made of weathering and erosion in determining relative age of the several drift sheets. It also dealt with the most important qualifying conditions that affect estimates.

At the close of the reading of this paper, at 12.30 o'clock, adjournment was taken, discussion being postponed to the afternoon.

The Society convened again at 2 o'clock, President Calvin presiding, and took up the discussion of Mr Leverett's paper, the participants being A. Penck, S. Calvin, F. Leverett, G. F. Wright, and G. K. Gilbert.

The next two papers were then read:

GLACIAL PHENOMENA OF SOUTHEASTERN WISCONSIN

BY WILLIAM C. ALDEN[1]

[*Abstract*]

A graphic presentation by a map 9 by 10 feet, scale 1 mile per inch, of a detailed study of the deposits of the Green Bay and Lake Michigan glaciers and associated phenomena of late Wisconsin glaciation of southeastern Wisconsin. The map represents an area approximately 8,600 square miles, which has been studied by the author under the direction of Dr T. C. Chamberlin during the greater part of the last ten years. The presentation comprised such description as the time permitted of the conditions affecting the advance of the two glaciers, their relations to each other, the character, distribution, and mode of formation of the several deposits, terminal and recessional moraines, outwash deposits, ground moraines, drumlins and eskers, the lithological composition of the drift and its significance. Evidence was presented by a deposit of red till of a later readvance of the two glaciers southward to the vicinities of Milwaukee and Fond du Lac. The shorelines and deposits of lake Chicago and succeeding glacial lakes were also shown.

CRITERIA FOR DISCRIMINATION OF THE AGE OF GLACIAL DRIFT SHEETS AS MODIFIED BY TOPOGRAPHIC SITUATION AND DRAINAGE RELATIONS

BY WILLIAM C. ALDEN[1]

[*Abstract*]

The discussion was confined to phases illustrated by the pre-Wisconsin drift of southern Wisconsin and northern Illinois.

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[1] Introduced by T. C. Chamberlin.

Character of this drift and reasons for regarding the drift exposed at the surface throughout this area as belonging to one and the same sheet. The lithological composition and its significance, directions of ice movement, absence of intercalated weathered zones, soils, or vegetable deposits.

Differences in the apparent amounts of surface modification of this drift in different parts of the area which might be regarded as indicating differences in age:

1. Topographic relations and amount of erosion.
2. Weathering, leaching, and oxidation. The occurrence in places of thoroughly disintegrated drift or residual till; in others, of drift but moderately leached and oxidized; in others, of perfectly fresh unmodified drift at the surface or immediately below the loess.

The reasons for these differences:

1. Influence of pre-Glacial topography on drainage slope and upland of the drift. Influence of the Saint Peter sandstone on the pre-Glacial topography. Relations of surface wash to the apparent amount of surficial leaching and oxidation.
2. The post-Illinoisan diversion of Rock river below Rockford, Illinois, and the consequent retardation of erosion due to the work of cutting new rock gorges at several cols. Removal of the weathered drift from slopes with preservation on the uplands.

Necessity for caution in the discrimination of distant drift sheets in the absence of marked differences in lithological composition or of sections showing overlapping drift with intercalated soils, vegetable deposits, or weathered zones.

The two papers together were discussed by F. Leverett.

Then was read

LAKE OJIBWA, LAST OF THE GREAT GLACIAL LAKES

BY A. P. COLEMAN

[*Abstract*]

As the Labrador ice-sheet retreated north to the watershed between the Great lakes and James bay, the waters now flowing northward were impounded, first as a narrow bay of lake Algonquin opening south past Sudbury, afterwards as a separate lake with an outlet down the Ottawa valley. This lake probably existed during the time of the Nipissing Great lakes, and was the last of the ice-dammed lakes. The elevation of its outlet is now 900 feet, but was then much lower. In its bed the "clay belt" of northern Ontario and Quebec was deposited, having an extent of over 25,000 square miles. The maximum area covered by its waters must have been greater than that of lake Superior; though probably its extent varied greatly in accordance with the position of the ice front.

This paper was discussed by F. B. Taylor and A. P. Coleman.

The next paper read was

GLACIAL EROSION ON KELLEYS ISLAND, OHIO[1]

BY FRANK CARNEY

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INTRODUCTION

All are familiar with the conventional cross-section of a valley deepened by glacial erosion. This paper aims to show (1) that wherever we have concentrated glacial erosion in rock, the result, whether a groove a few inches deep or a modified valley over-deepened several hundred feet, is a U-profile; (2) that the grooves on Kelleys island were cut in a very short time; that the tools were largely of limestone of the formation being eroded, and that the work was done not long before the ice melted back permanently from the island.

This island is located about 6 miles off the mainland. Its area is approximately 7 square miles, and it lies north of the axis of the Lake Erie ice lobe. Its surface consists of limestone bearing a slight veneer of glacial drift. Locally the drift has been assorted by wave action of the lake at a higher level, leaving beach gravels at the foot of the cliffs cut in the limestone.

The region has long been known for its quarries as well as for its unusual glacial erosion features. At the present time there are three principal workings, designated the North, West, and South quarries (figure 1), operated by the Kelley Island Stone and Transport Company.

Between the West and the South quarries, during the past summer, an area about 100 rods long and 4 rods wide was stripped preparatory to opening up a new quarry.[2] This surface, which lies transverse to the direction of ice motion, was covered by from 3 to 6 feet of glacial drift. This recently exposed area of limestone presents features of ice work which, when considered in connection with the scoring and grooving near by on the island, suggest some interesting questions in glacial erosion.

The area represented in figure 1, plate 108, looks northward over the area, which up to a point in the distance where the rock surface appreciably rises is completely smoothed and striated (figure 2, plate 108), presenting, for the most part, a perfectly flat surface. Toward the north end, however, is a depression in this otherwise flat expanse; a few rods beyond this depression the glaciated surface is displaced by a rising slope of limestone which shows no evidence whatever of ice work. Furthermore, the camera stands on rough limestone that does not give the slightest indication of ice erosion. The smoothly polished area intervening is 830 feet long. A little more than three

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[1] Presented with the permission of the Ohio Geological Survey, it being understood that the author is responsible for the opinions expressed.

Manuscript received by the Secretary of the Society on February 24, 1909.

[2] My attention was called to this new exposure by Mr C. R. Stauffer.

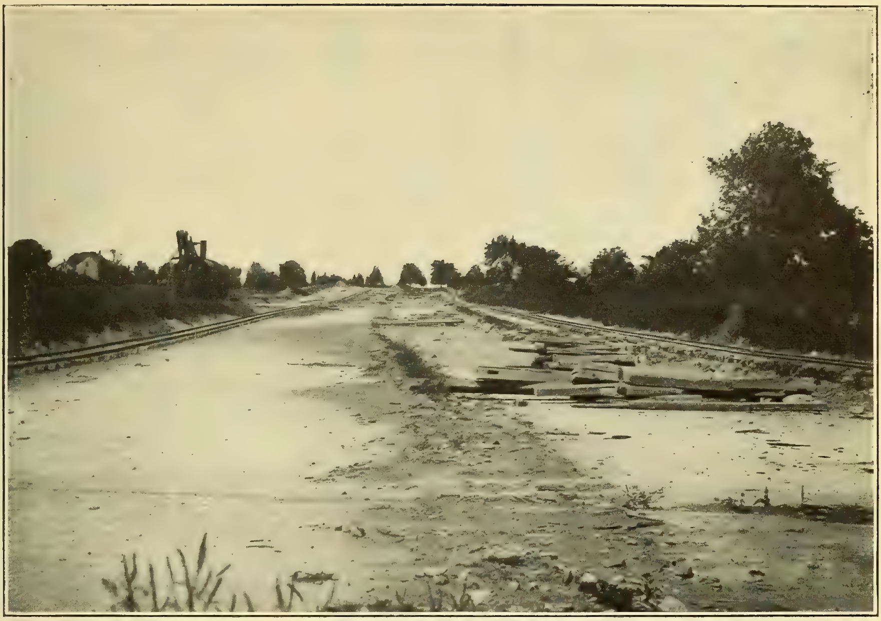

Figure 1.—Surface on Kelleys Island recently stripped for Quarrying

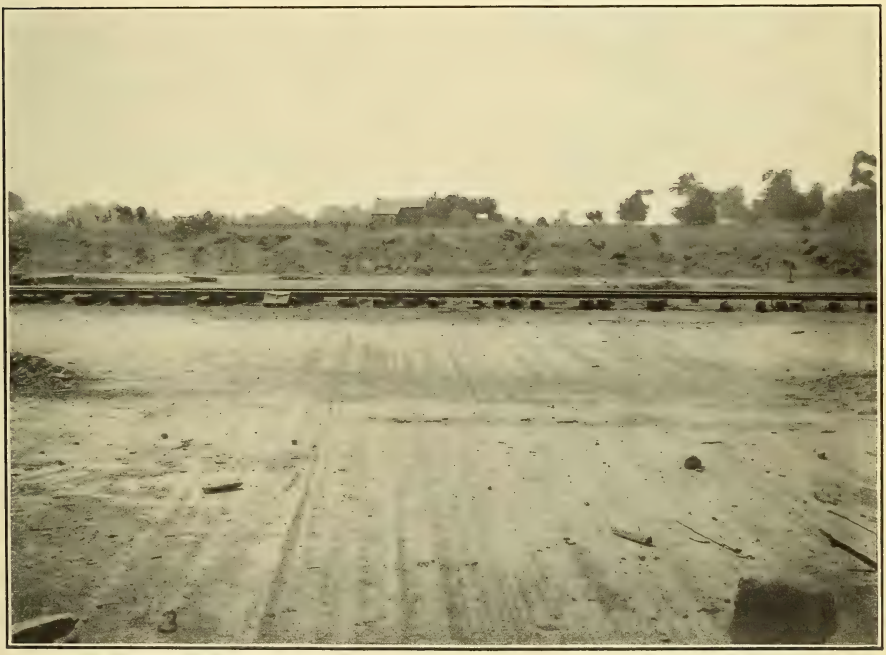

Figure 2.—Detail of the glacial Scoring on the recently stripped Area, looking West (C. R. Stauffer, Photographer)

GLACIAL PHENOMENA ON KELLEYS ISLAND

quarters of a mile north is located the deeply grooved limestone that is classic among the better known areas of glaciation;[3] these grooves (figure 1, plate 109) are quite regular in horizontal extension; their original length is not known because of partial obliteration by quarrying. The details of this grooving will be considered later.

Northward from the area under discussion the limestone at the West quarry also shows plainly the work of ice, but not in the marked degree seen at the North quarry; the rock is scored and striated and contains some shallow grooves.

The drift on the island wherever exposed consists almost entirely of clay and of limestone blocks. In several exposures, studied closely, erratics were rare.

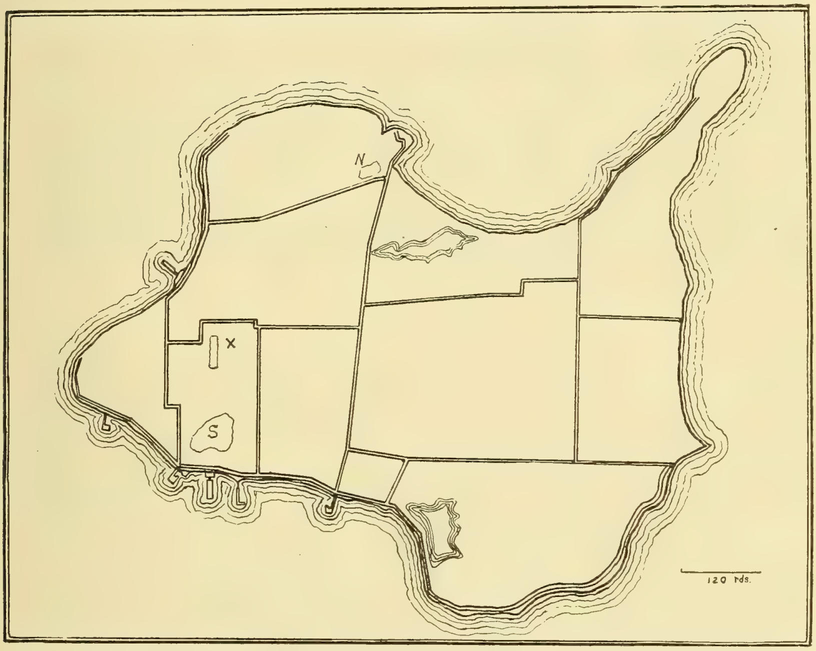

FIGURE 1.—*Kelleys Island, Ohio*

The South quarry is indicated by S; the North quarry by N; the recently stripped area by X.

DISCUSSION

A north-south section of the island through the areas above described shows a striking variation in the intensity of ice erosion. Not only does its intensity vary from place to place, but the change is abrupt. A surface of uneven and unpolished limestone might be due to the effects of weathering in post-Glacial times. In localities where the drift is very thin and freezing in consequence had penetrated the rock, the irregular condition of the limestone may represent normal disintegration; some of the rough surfaces observed might be thus accounted for. In the area recently stripped, however, the depth of the drift precludes this explanation. So far as it is possible to tell, the area over almost its entire length was protected by a uniform mantle of debris. This sudden transition from polished to irregular and rough surfaces can not be accounted for by the effects of post-Glacial weathering.

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[3] G. K. Gilbert: Surface geology of the Maumee valley. Geological Survey of Ohio, vol. i, 1871, p. 538.
T. C. Chamberlin: Seventh Annual Report, U. S. Geological Survey, 1885, pp. 211-216.
G. F. Wright: Ice age in North America, 1889, pp. 232-238.

Fickleness in the abrasion work of glacier ice is an old observation. Surfaces which lithologically should register the striations of rock-shod ice are frequently without this evidence; several miles of such outcrops are known. But when ice passes over limestone horizons we expect to find it registering the slightest work of tools carried in its basal area; where such horizons have been protected from weathering during post-Glacial time by drift, even the weak striæ should now be seen. Irregularity in the intensity of glacial scoring, or even its presence and absence over long distances, is not remarkable. But when this variation is found within a mile it arouses our interest; furthermore, when the variation is so striking, as is the case on Kelleys island, we would seek an explanation.

For several square miles about Sandusky limestone outcrops. The numerous islands in this region are evidence of pre-Glacial stream erosion topography, modified to some extent by ice work.[4] This irregular surface lies apparently not far from the axis of the Erie basin, and therefore has the proper exposure for inviting active ice erosion. On Marblehead, at least, it was observed that the major joint planes are but slightly discordant with the direction of the moving ice (figure 2, plate 109). Under these conditions it is apparent that locally the basal parts of an ice-sheet might be overloaded even to the point of becoming stagnant.[5] Such a mass of stationary ice would interfere with the movement of the ice immediately in its rear. At first this coming ice would be checked, but later it would move upward, shearing across the stagnant area. As the overloaded mass gradually lost velocity, the zone of ice directly above it moved onward or sheared over it; the ice in the rear on moving upward proceeded with this ice. The weight of the superincumbent mass would account for a downward movement on the leeward side of the stagnant area. If this downward moving line of ice were properly shod with debris, the rock surface beneath it would suffer unusual erosion; thus the surface on the leeward side of a stagnant area under these conditions would be strongly glaciated.[6]

An overloaded mass of ice loses its velocity gradually, for it acquires its load gradually; in consequence of this the rock surface covered as the mass reaches the stage of stagnation does not suffer further abrasion, at least not until after this stagnant mass has been removed, probably through being grad-

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[4] J. S. Newberry says: "They are all wrought by glacial action." Geological Survey of Ohio, vol. 1, 1873, p. 111.

[5] Chamberlin and Salisbury: Geology, vol. i, 1904, p. 271.

[6] Chamberlin, in discussing the "Removal of scoring debris from action," mentions that in the opinion of some glacialists there may be an "upward movement through the body of the glaciers." Seventh Annual Report, U. S. Geological Survey, 1885, p. 239.

Chamberlin and Salisbury: Loc. cit., p. 282.

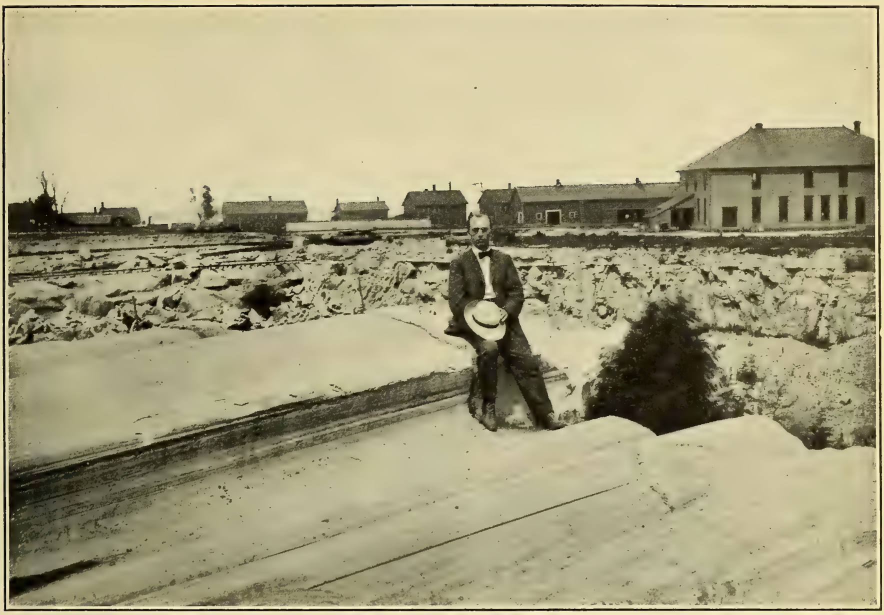

Figure 1.—General View of a grooved Surface of Kelleys Island

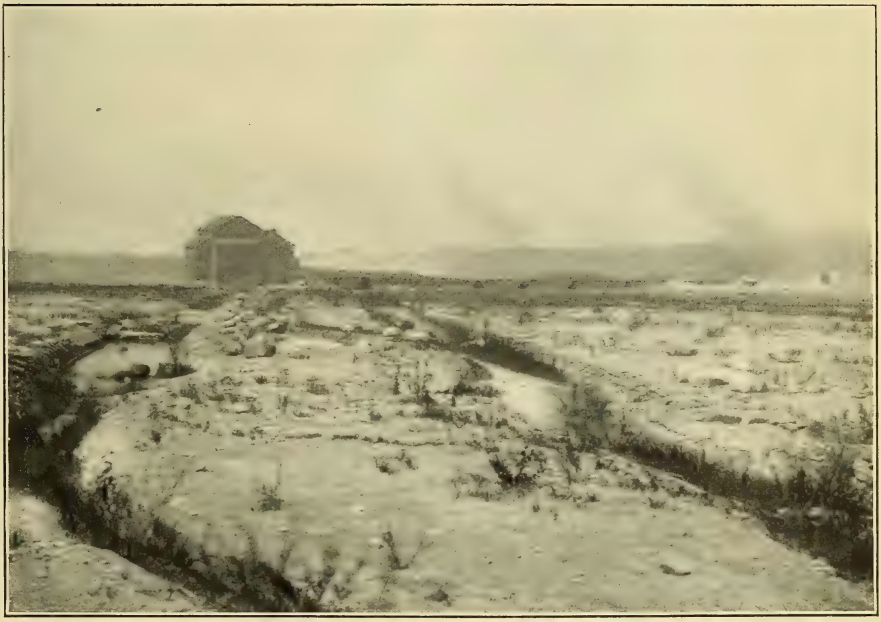

Figure 2.—Glacial Corrasion on Marblehead Peninsula, suggesting a relationship to major joint Plains

GLACIAL PHENOMENA ON KELLEYS ISLAND

ually pared off along the shearing planes developed over its surface. It is possible that in the course of time these shearing surfaces may be so lowered as to gradually carry away the entire mass of stagnant ice. During the period of stagnation the surface immediately covered was protected from further ice action. In accordance with the above discussion, this surface could not have been much scored in the process of overloading; but previously it may have been striated. Furthermore, it is possible that the gliding surface once established may persist, and the overloaded mass become, in effect, a part of the bed over which the glacier continues to move.

So far we have discussed only the conditions observed in a longitudinal cross-section of the ice. The basal ice on either side of this overloaded lens, immediately contiguous, lost velocity; here, too, shearing planes were developed, and the ice laterally moved with the general basal trend. If this ice were properly shod with rock, the surface beneath it would suffer abrasion; so under these conditions there might be an area on all sides of which the rock surface has been smoothed and striated. Remembering, however, that debris in an ice-sheet is not apt to be homogeneously distributed, such general erosion is seldom the case.

As the ice may carry a plentiful supply of tools in a narrow longitudinal band at its base, and adjacent to this band be relatively free of rubbish, we might find just such a relation of surfaces as are shown in figure 1, plate 108. The fact, however, that glacially scored surfaces are interrupted in the line of ice motion by unscored surfaces gives much significance to the theory of upward and downward movement of currents within the ice-mass. We have long known that the erosive work of rivers is accomplished largely by such secondary currents, which are accessory to the main flow of the river. It seems not unreasonable that in an ice-sheet there may exist similar secondary currents, occasioned also by irregular topography, and that when these lines of accentuated flowage bear a reasonable amount of tools they may do unusual erosive work.

Direction of Ice Motion

Data on the direction of ice motion in this region was collected on Marblehead, on Kelleys island, and on Point Pelee island, about 10 miles north of Kelleys island. For part of this information I am indebted to Mr C. R. Stauffer.

In the first area the irregular channels shown in figure 2, plate 109, read south 76 degrees west, conforming with the general direction of the major joints.

On Kelleys island, at the North quarry, the grooves read south 73 degrees west. At the recently stripped area south of this quarry two sets of striæ are conspicuous, the older varying from 1 degree to 8 degrees south of west, with very many east-west readings, while the latest ice movement varies from 23 degrees north to 23 degrees south of west; thus there is some divergence in both the older and more recent direction of ice motion.[7] At the West quarry the general direction of striæ is south 75 degrees west. A surface between the

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[7] F. Leverett gives readings of other striated areas in this part of Ohio. Monograph XLI, U. S. Geological Survey, 1902, pp. 423-424.

West and South quarries bears striæ reading south 60 degrees west; these are intersected by lines south 85 degrees west.

On Point Pelee island the older sets range about south 60 degrees west, while the more recent are east-west.

Perhaps neither of these two sets of striæ represents the movement of the general ice-sheet during either the advancing or the maximum stage; it is more probable that all this scoring is the work of the glacier after it has ceased to advance. Whatever grooving and polishing had been accomplished by the ice at earlier stages was either modified or obliterated by the action of the Erie Lobe stage, when the Erie basin was occupied by a deploying lobe of ice. In this area, then, constancy in direction of striæ would be found only along or very near the axis of the lobe. Laterally from this axis the earlier set would be more generally east-west, but as the front of the ice successively took new positions the last movement over a given place off the axis was outward from the axis, thus imposing on the east-west set striæ trending to the north or to the south. The Erie lobe was associated with ice from the Labrador dispersion center. The general motion of the ice through this basin should, therefore, be south of west. The fact that we have some readings north of west, and many readings more nearly east-west, indicates that the Erie Lobe axis was a little south of Kelleys island. On this supposition, then, the east-west readings and those approximately east-west represent the more general motion of the Erie lobe, whereas the other readings are due to the deployment at a later stage.

The more vigorous scoring, particularly the grooves, shows less diversion from the east-west line.

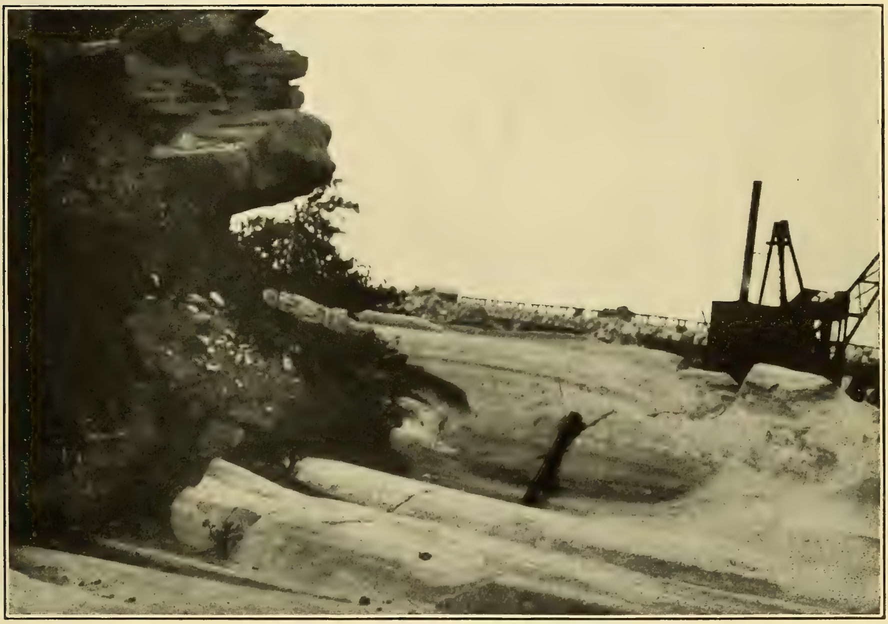
Some of the surfaces from which these readings were taken are so completely covered with very fine scratches that one can not state with absolute certainty the order in which the striæ were made.

The Deep Grooves

A cross-section of this grooved surface (figure 1, plate 109) is a half-oval figure. The apex drops off into the quarry; therefore the original shape of the cross-section can not be given. The outline preserved suggests somewhat the roche moutonnée type of erosion surface.

The prevailing cross-section of the individual grooves is U-shaped. The grooves are sharply defined, almost mechanically precise in outlines. The north side of one of the grooves overhangs. On all of the surfaces, both in the grooves and on the areas between the grooves, are delicate striæ, with only now and then a harsher line. There is very little evidence of chatter abrasion, and only one conspicuous gouge was noted. Plate 110 shows an area where the tools diverged from the straight line and produced a fluting effect; the rock surface around which the tools moved appears no harder than the rock elsewhere.

A simple explanation for these great grooves, one that is not uncommonly given, is to account for them by the lathe-like effect of the large boulders held in the bottom of the ice. A closer analysis, however, leads to the following conclusions: (1) The vigorous scoring indicates a localization of tools and a constant supply of them in the basal area of the ice; the source of this supply



BULGING IN A GROOVED SURFACE ON KELLEYS ISLAND, OHIO

evidently was near at hand, for the sharp-cut details of striation indicate freshness of the tools; (2) the country rock is not appreciably harder than the tools used in carving it; this conclusion is arrived at partly because of the absence of crystallines in the neighboring drift, also because tools secured from a more distant source probably would have suffered much from abrasion in transit, thus losing the sharper outlines and becoming less liable to produce the accurately defined striæ above described; furthermore, there is positive evidence in the drift that the local limestone was the chief source of the debris; (3) these grooves indicate a concentration of erosive processes within a narrow limit, or, better, a superimposed alignment of striæ, causing at first a depression below the general level of the rock surface; (4) the basal ice under pressure moulded itself to the slight depression thus made; in consequence there was further localization of mechanical work. That the ice continued to fit the grooves as they were deepened is shown in the fact that the sides of the grooves are delicately striated, and in the further fact that in one groove at least there was such a continued supply of tools as to cut the wall back farther and farther, producing an overhanging condition. All parts of this overhanging wall are striated.

SUMMARY

Cumulative observation has shown (1) that glacier ice, of either the continental or alpine type, when moulded to or confined within a valley, changes its subaerial and water-erosion profile to a U-shaped cross-section; (2) that this ice continuing to occupy such a valley is competent to overdeepen it hundreds of feet.

The grooves on Kelleys island show that when tools are so localized in the basal ice as to abrade continuously within a narrow limit, say a few inches, the result shortly is a shallow elliptical depression, and, later, the action continuing to be localized, a U-shaped trough, which may become deeper than broad. The weight of the ice mass keeps it moulded to the growing groove, which is enlarged so long as cutting tools, even grains of sand, are present. This behavior of ice is somewhat analogous to the response of a plastic substance under pressure; in consequence the tools grind and scour laterally as well as on the bottom of the groove. When ice feeds alpine-like through a valley, or when the movement of an ice cap trends with a valley, overdeepening will inevitably follow if the ice carries tools in contact with the valley walls.

The paper was discussed by G. F. Wright.

Then was read

CHALK FORMATIONS OF NORTHEAST TEXAS

BY C. H. GORDON

[*Abstract*]

Extending in a west to east direction across the southern part of Lamar county, and thence northeast through Red River county to Red river, and having a width of from 1 to 3 miles, is a belt of chalk known as the Annona chalk, from the town in Red River county near which it outcrops. In the earlier publications relating to the Cretaceous of Texas this formation was considered as the diminished representative of the Austin chalk of central Texas. Later authors, however, have contended that it represents a higher horizon, and belongs within the so-called Navarro division of the Upper Cretaceous.

Recent investigations by the author, in connection with the study of the underground waters of northeastern Texas, tend to confirm the earlier view as advanced by Taff that the Annona is the northeastward extension of the Austin formation. Tracing the outcrop of the Annona westward, it was found to merge with that of the Austin as exposed in the vicinity of Honey Grove and westward to Sherman. At Austin the formation has a reported thickness of about 600 feet, and is composed essentially of chalk throughout. Toward the northeast the lower beds become marly, the thickness of the chalk marl increasing until in the vicinity of Red river the marls have a thickness of about 400 feet. To this part of the formation, as represented in northeastern Texas and southwestern Arkansas, Hill applied the name Brownstown beds.

The relations seem to indicate that at the beginning of the Austin epoch the conditions for the formation of pure chalk existed only in the region about Austin, but with the progress of time they were extended farther and farther northeast as a result possibly of a change in the relative position of land and sea.

The next paper was read by title:

GEOLOGIC HISTORY OF THE OUACHITA REGION

BY E. O. ULRICH

After which was read

RESULTS OF A RECENT INVESTIGATION OF THE COASTAL PLAIN FORMATIONS IN THE AREA BETWEEN MASSACHUSETTS AND NORTH CAROLINA[1]

BY WILLIAM BULLOCK CLARK

[*Abstract*]

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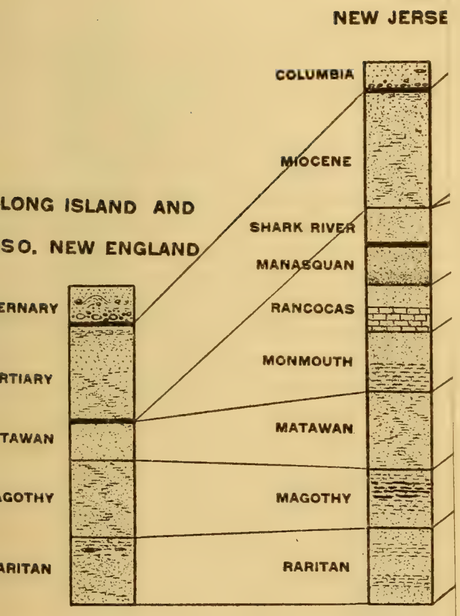
[1] Published by permission of the Director of the U. S. Geological Survey. Messrs B. L. Miller, L. W. Stephenson, E. W. Berry, and A. B. Bibbins and Miss J. A. Gardner have been associated with the author in this work.

Manuscript received by the Secretary of the Society May 26, 1909.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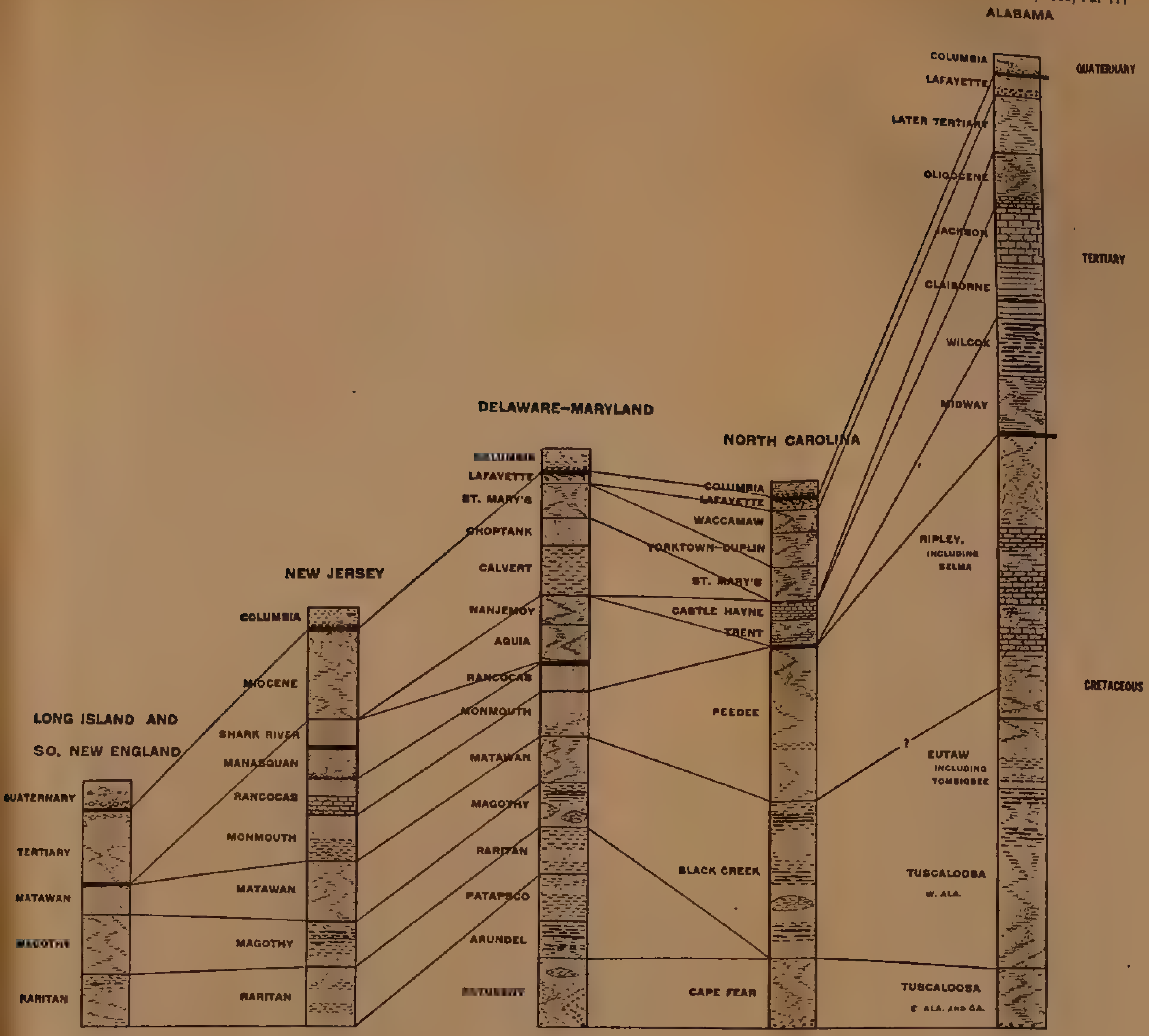
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PATUXENT
NORTH CAROLINA
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COLUMBIA
LAFAYETTE
LATER TERTIARY
OLIGOCENE
JACKSON
CLAIBORNE
WILCOX
MIDWAY
RIPLEY,
INCLUDING
SELMA
?
EUTAW
INCLUDING
TOMBIGBEE
TUSCALOOSA
W. ALA.
TUSCALOOSA
E. ALA. AND GA.
QUATERNARY
TERTIARY
CRETACEOUS

COMPARATIVE COLUMNAR SECTIONS OF ATLANTIC COASTAL PLAIN FORMATIONS

GENERAL CHARACTERISTICS OF THE FORMATIONS

The progress of the investigation of the formations of the middle and northern Atlantic Coastal Plain region furnishes little by little a clearer interpretation of the geology of that area. The deposits as a whole have been but little changed since they were originally laid down along the coastal border, but the strata present much complexity due to the variation in the angle and direction of tilting during the successive oscillations of the sea floor. The sediments in general form a series of thin sheets which are inclined seaward, so that successively later formations are encountered in passing from the inland border of the region toward the coast, yet at no place accessible to our study do we find a complete sequence of deposits, although sedimentation must have been continuous over a large part of the continental shelf. The incompleteness, therefore, must be regarded as a purely marginal condition due to the transgressions and retrogressions of the sea along the coastal border.

The correlation table given on the accompanying plate shows the relations of the several formations throughout the northern and middle Atlantic Coastal plain and their approximate equivalents in the eastern Gulf region.

CRETACEOUS

The Cretaceous formations constitute the basal deposits of the Coastal Plain series along the line of outcrop. Well borings throughout the district have not afforded strata of earlier age, although they may exist to the eastward toward the margin of the continental shelf.

LOWER CRETACEOUS

Deposits of Lower Cretaceous age are most extensively developed in Maryland and northern Virginia, where the Patuxent (arkosic sands, gravels, clays), Arundel (clays, lignites, carbonate of iron concretions), and Patapsco (variegated clays, sands) formations occur. The organic remains consist for the most part of dinosaurs and plants. Lull, who has recently studied the former, and Berry, who has been engaged in an investigation of the latter, are agreed that they are of Lower Cretaceous age, so that the earlier questionable reference of the Patuxent and Arundel formations to the Jurassic is now abandoned. Farther southward in North Carolina is the Cape Fear formation (arkosic sands, clays), so called by Stephenson, which is evidently continuous with the Patuxent formation, although the basal beds of the Coastal plain are transgressed by later formations in southern Virginia and northern North Carolina. No fossils have been found in the Cape Fear formation, but the strata are similar lithologically to the Patuxent farther north and unlike the Arundel and Patapsco.

UPPER CRETACEOUS

Upper Cretaceous deposits extend from New Jersey, where they are most extensively developed, northeastward along the New England coast and southward through Delaware and Maryland to the Potomac valley. Strata of this age have been penetrated in well borings in eastern Virginia, but do not appear along the line of outcrop, being overlapped by Tertiary formations. In North Carolina Upper Cretaceous deposits again appear, and cover a wide area to the south of the Hatteras axis.

The Raritan formation (clays, sands, gravels) of the northern part of the Coastal plain evidently represents the earliest phase of Upper Cretaceous deposition, these beds overlying the Lower Cretaceous strata, where exposed, with a marked unconformity. Beds of similar age do not occur in North Carolina.

The overlying Magothy-Matawan formations (sands, clays, lignitic and glauconitic beds), which outcrop throughout the area from the Potomac basin northward to the islands off the New England coast, are represented in North Carolina by the Black Creek formation (sands, clays, lignitic and glauconitic beds), the same fauna and flora characterizing the deposits in both areas. The minor subdivisions established in New Jersey, where these formations are best developed, can not be recognized elsewhere, and the changes in physical conditions bringing about the differentiation of faunules there described were evidently only local.

The Monmouth formation (glauconitic beds, sands, clays) characterized by the introduction of *Belemnitella americana* and other forms can be traced through New Jersey, Delaware, and Maryland, and again reappears in North Carolina, the deposits here and in South Carolina having been named the Peedee formation (glauconitic beds, sands, clays). The reappearance of one of the earlier faunules toward the close of the Monmouth, as observed in New Jersey, is wanting.

The Rancocas and Manasquan formations (glauconitic and calcareous beds) of the northern part of the Coastal plain are chiefly found in New Jersey and Delaware, and contain a younger fauna. Such late Cretaceous strata are not known elsewhere along the Atlantic border.

TABLE OF CRETACEOUS FORMATIONS

	Long Island and southern New England	New Jersey	Delaware and Maryland	Virginia	North Carolina	Alabama
Upper Cretaceous		Manasquan				
		Rancocas	Rancocas			
		Monmouth	Monmouth		Peedee	Ripley
	Matawan	Matawan	Matawan		Black Creek	Eutaw
	Magothy	Magothy	Magothy			Tuscaloosa (West Ala.)
	Raritan	Raritan	Raritan			
Lower Cretaceous			Patapsco	Patapsco		
			Arundel			
			Patuxent	Patuxent	Cape Fear	Tuscaloosa (East Ala.)

TERTIARY

RELATION OF TERTIARY TO CRETACEOUS FORMATIONS

The Tertiary formations overlie the Cretaceous formations unconformably, and at times transgress them, the Tertiary strata in such instances resting directly on the crystalline rocks of the Piedmont plateau.

EOCENE

The Eocene deposits of New Jersey, known as the Shark River formation (glauconitic beds), apparently overlie the Manasquan formation conformably. The contained fossils show the beds to be of early Eocene age. Farther south in Maryland and Virginia, but nowhere in contact with the Shark River beds, is a series of younger and conformable Eocene deposits known as the Aquia and Nanjemoy formations (glauconitic beds, clays, sands), which overlie the Cretaceous unconformably. Entirely discontinuous are the North Carolina Eocene strata, which Miller has named the Trent and Castle Hayne formations (calcareous marls, clays), and which are of still later Eocene age. The latter are apparently unconformable to each other, and likewise rest unconformably on Cretaceous deposits.

MIOCENE

The Miocene deposits are best developed in the Chesapeake Bay region, where four formations have been recognized, known as the Calvert (clays, sandy clays, diatomaceous earth, shell marls), the Choptank (sandy clays, sands, shell marls), the St. Mary's (sandy clays, sands, shell marls), and the Yorktown (fragmental shell marls, sandy clays, sands). The Choptank does not occur in Virginia, and the Yorktown is absent in Maryand. These formations are evidently continued in part into New Jersey, as similar faunas have been found there, but the relationships have not been fully worked out as yet. To the southward the St. Mary's and Yorktown formations, transgressing the earlier deposits, continue on into North Carolina, both being found over extensive areas to the north of the Hatteras axis, where the Yorktown overlies the St. Mary's unconformably. To the south of the Hatteras axis deposits very similar to the Yorktown formation, both lithologically and paleontologically, but known under the name of the Duplin formation, are found resting unconformably on pre-Miocene formations.

PLIOCENE

The Pliocene deposits are of two types: (*a*) the marine beds, called the Waccamaw formation (clays, sands, shell marls), and confined to a narrow belt on the eastern margin of the Coastal plain of North Carolina; (*b*) the terrace deposits found along the higher portions of the Coastal plain, and known as the Lafayette formation (gravels, sands, loams). The terrace is more dissected than the later Pleistocene terraces. The Lafayette formation is most extensively developed in Maryland and Virginia. In Delaware and Pennsylvania on the north and North Carolina on the south it is very fragmentary.

TABLE OF TERTIARY FORMATIONS

	Maryland	Virginia	North Carolina
Pliocene	Lafayette	Lafayette	Lafayette
			Waccamaw
Miocene		Yorktown	Yorktown and Duplin
	St. Mary's	St. Mary's	St. Mary's
	Choptank		
	Calvert	Calvert	
Eocene			Castle Hayne
			Trent
	Nanjemoy	Nanjemoy	
	Aquia	Aquia	

QUATERNARY

The Quaternary deposits overlie the older Coastal Plain formations as a surficial cover, and embrace a large part of the country from the Piedmont border to the coastal margin. They represent the most recent phase of deposition, and still preserve largely their original form. Physiographic criteria, therefore, are of much importance in interpreting and correlating the deposits.

PLEISTOCENE

The Pleistocene deposits consist chiefly of a series of terraces, the earliest found along the western border of the Coastal plain, encircling the margin of the Piedmont plateau and the higher elevations of the Coastal plain, and extending up the estuaries and streams, where it finally merges into fluviatile deposits. This oldest terrace, known as the Sunderland formation, can be traced from the glacial deposits southward across Maryland and Virginia into North Carolina. The Sunderland terrace, which has an elevation of 150 to 200 feet along its shoreward margin, declines gradually seaward and toward the larger valleys, where it reaches to below 100 feet in height. Another terrace is found in central and southern North Carolina between the Lafayette and Sunderland.

The next younger terrace, known as the Wicomico, encircles the preceding terrace at a lower elevation, and forms a well marked belt along the eastward margin of the latter, although extending up the river channels in some places to the Piedmont border, where it also merges into fluvatile deposits. Its landward margin has an elevation of 80 to 110 feet, from which point it declines seaward and toward the larger stream valleys to 50 to 60 feet in elevation. Its surface is not as extensively dissected as the Sunderland terrace, and near its inner margin are found many buried valleys that were cut at the close of Sunderland time.

Below the Wicomico terrace, and encircling it, is the third or youngest terrace of the Pleistocene, which has been called the Talbot. The landward margin of the Talbot terrace is from 40 to 60 feet in height, from which elevation it gradually declines seaward until it reaches nearly, if not quite, to sealevel. The Talbot terrace has been but slightly dissected, compared with the earlier terraces, and forms the coastal lowlands. It may also be traced as a low terrace far up the estuaries and river valleys until it also merges into true fluviatile deposits. In North Carolina it divides into two terraces, constituting the Chowan and Pamlico formations.

All of these Pleistocene formations have been traced step by step throughout the area in question, and present the same general characters everywhere.

RECENT

The Recent deposits consist of beaches, sand bars, sand spits, sand dunes, flood plains, and other fluviatile deposits and humus. These deposits represent the results of all the geological agencies now at work in modifying the surface of the Coastal plain, and are variously developed in the different portions of the region, dependent on the character of the adjacent formations and the distribution of the various streams and currents. A great Recent terrace, similar in all particulars to those of Pleistocene date, is now being laid down beneath the bed of the present sea and estuaries and along the border of the coast and tidal streams. Beaches are frequently being formed, while great sand bars are common. Sand dunes adjoin the coast, and are especially prominent in southern Virginia and North Carolina, where from cape Henry southward they are a conspicuous feature of the coastal topography. The rivers during flood are constructing flood plains, which coalesce with the deposits of the estuaries. Over the land surface the transfer of material and the development of soils, with their accompanying humus, is going on everywhere.

Comparison of the Atlantic Coast Formations with those of the Gulf and other Areas

The geology of the Gulf region presents many points of difference from that of the Middle Atlantic Coast district, and yet certain comparisons may be instituted on the basis of the faunas and floras by which a correlation of the deposits in the two areas may be in many instances satisfactorily determined. The similarity of materials is much more marked in the lower portions of the series than in the upper, the Cretaceous and Eocene formations affording many beds of like character and containing similar faunas. The later Tertiary deposits show marked differences, both in materials and fossils, and little attempt has been made to correlate the strata. Comparisons likewise have not been made in the case of the Quaternary formations.

A correlation of the Cretaceous deposits of the Atlantic coast with those of the eastern Gulf cannot be in all instances satisfactorily made, since the Gulf Cretaceous series has never been worked out in detail, and much yet remains to be done in the determination of the range of the species. Strata hitherto called Tuscaloosa are found at the base of the Cretaceous series, in eastern

Alabama as well as in Georgia, which must be regarded as identical with the Patuxent-Cape Fear formations of the Atlantic border. There is a marked unconformity at the top of the beds, and deposits supposed to represent the Eutaw, or possibly in part the Tuscaloosa farther west, are found above. Little is known regarding the western extension of these lower beds, although it is possible that they may be found beneath the surface in central Alabama, and perhaps farther westward. These older beds are, so far as known, unfossiliferous, but are now regarded as belonging unquestionably to the Lower Cretaceous.

Reference has already been made to the fact that the Magothy-Matawan-Monmouth formations of the northern part of the Coastal plain are to be correlated with the Black Creek-Peedee formations of North Carolina. It seems equally certain that these find their counterpart in the Tuscaloosa-Eutaw-Ripley of the eastern Gulf, with the exception of such portion hitherto referred to the Tuscaloosa as is known to be of Lower Cretaceous age.

Very little is known of the fauna of the earliest marine sediments commonly referred to the Eutaw, although the few fossils found come from apparently interstratified marine beds not unlike those in the Black Creek and the Magothy. It is also apparent that the fauna of certain strata of the lower portions of what has been regarded as Ripley, on the Chattahoochie river, represents the Black Creek and the Magothy-Matawan, but whether these beds should be considered Ripley or as representing part of an earlier horizon, and thus included in the Eutaw, can only be determined by further investigations.

It is largely a question, in any event, as to whether the term Ripley or Ripleyan shall be used in a broad way to include the beds containing both the lower and upper faunas, in which case even the Eutaw would have to be regarded as Lower Ripley, or whether two formations are to be recognized to be called Ripley and something else, either Eutaw or Tombigbee, as certain stratigraphic and paleontologic facts suggest. Continuous sedimentation, with gradual change in the character of the materials until the beds became wholly or at least largely marine, doubtless continued during the life of these faunas here, as in the other areas, and such facts as are available point to this conclusion. Such being the case, the term Ripleyan might perhaps with greater propriety be applied, as has been frequently done to the entire fauna, if it seemed inadvisable to restrict it, in which event a new formational name would have to be employed for the upper beds. It is evident that the greater part of the deposits comprising the Tuscaloosa must of necessity be associated with the Upper Cretaceous strata of the Gulf region, and a group term to include this entire series of deposits would not be inappropriate. A final decision on these points, as well as a satisfactory correlation of the Middle Atlantic with the Eastern Gulf deposits must be deferred, however, until more is known of the stratigraphy and paleontology of the latter region.

When a comparison of the Atlantic Coast Cretaceous fauna is made with that of the European Cretaceous we find that its general character is that of the Senonian, and the view has been commonly held by invertebrate paleontologists that all of the marine beds of the Atlantic and Eastern Gulf coasts represent that epoch of the Cretaceous, with the possible exception of certain later deposits in New Jersey which have been regarded by the writer and others as of Danian age. Some even include in the Senonian all of the Upper Cretaceous strata, both marine and non-marine, from New Jersey to the Mississippi basin, since even the lowest known Upper Cretaceous deposits in this area (Raritan formation) contain a few marine invertebrates of possibly identical species with those of higher horizons. Those who hold this view necessarily consider that the earlier Turonian and Cenomanian epochs are unrepresented, since every one now agrees that the unconformably underlying deposits are Lower Cretaceous. It is quite possible, however, that a more exhaustive study of these faunas may show them to be in part of pre-Senonian age.

It is essential, however, before passing final judgment on the basis of marine invertebrates to examine the evidence furnished by the fossil plants which occur in great variety in the lowest beds beneath those containing the marine invertebrates, as well as in interbedded strata in the middle of the series. Berry, who has been engaged in a comparative study of the Cretaceous floras of the Atlantic and Gulf coasts, states that the Magothy-Black Creek flora is identical with that of the Tuscaloosa. Not only do they have the same floral characteristics, but the species are in a large number of instances identical. Furthermore, the same forms occur in the Woodbine formation in Texas and in the Dakota beds of the West. The flora has been regarded as characteristically Cenomanian, although it may represent the somewhat meager Turonian flora which succeeds it, and therefore belong to that horizon. On the other hand, it is distinctly older than the Montana flora of the West and its Senonian equivalent in Europe.

The evidence afforded, therefore, by the invertebrates and plants is apparently in conflict, since the former present a Senonian facies throughout, according to many invertebrate paleontologists, while the latter are regarded by paleobotanists to be characteristicaly Cenomanian, or possibly Turonian, in age. In this connection we find in the western Gulf that the Woodbine formation, which is the representative of the Dakota sandstone farther west, and which contains, as already pointed out, a Black Creek-Magothy-Tuscaloosa flora, is succeeded by marine beds known as the Eagle Ford and Austin Chalk formations, which represent the Colorado group farther west, and that these are again succeeded by deposits containing the Ripley fauna, the latter being regarded as the equivalent of the Montana group of the Rocky Mountain district. Since the Dakota has been generally regarded as containing a Cenomanian flora and the Montana a Senonian fauna and flora, the Colorado and its equivalents have been assigned to the Turonian. As the Montana flora is considered by paleobotanists as quite distinct from and much younger in its facies than the Dakota, it is difficult to see, if we are not to ignore the evidence of paleobotany, how, as some have supposed, the entire series of Upper Cretaceous sediments on the Atlantic and Eastern Gulf coasts can be assigned to the Senonian. Such a conclusion is still further weakened by the fact that the Woodbine beds may be stratigraphically continuous beneath the Mississippi embayment with the Tuscaloosa deposits farther east in which the same flora occurs. A much more exhaustive study of the stratigraphy of the Cretaceous deposits of the Central and Western Gulf regions is clearly demanded, therefore, before these questions can be finally settled.

It is apparent, in any event, that we are still forced to consider the possibility of the Upper Cretaceous sediments of the Atlantic and Eastern Gulf coasts representing horizons earlier than the Senonian. Since the Turonian has not been recognized by either a distinct fauna or flora in the series of conformable strata under consideration, it is quite possible that a Cenomanian flora, once established, continued its existence in America later than the close of the Cenomanian epoch in Europe. At the same time it is conceivable that the earlier elements of the invertebrate fauna are somewhat older than paleozoologists have recognized, and that a greater or less portion of the series under discussion must therefore be regarded as Turonian. The evidence of the plants is certainly favorable to this interpretation, as the European Turonian flora, although a very sparse one, presents some marked points of agreement with portions of the flora under consideration.

In conclusion, it may be well to direct attention to the fact that the use of the minor European time divisions of the Cretaceous in this connection, as has been often done, may well be questioned in any event, as it is clear from the conflicting evidence presented that it is impossible to assign sharply defined limits to them in the Atlantic and Eastern Gulf regions.

The Eocene deposits of the Atlantic Coastal plain show many points of similarity with those of the Gulf. The Shark River beds of New Jersey, which apparently overlie the Upper Cretaceous, conformably contain what is probably a Midway fauna, while the Aquia-Nanjemoy formations of Maryland, which are clearly unconformable to the earlier formations, contain a fauna that is distinctly Wilcox, and may be even in part Lower Claiborne. The Trent and Castle Hayne formations of North Carolina are of very late Eocene age, and so far as their molluscan forms are concerned suggest the Jackson, although Bassler has regarded the bryozoan species as Vicksburg, thus making those beds Oligocene in age. No such complete sequence of Eocene strata has been found in the middle and northern Atlantic Coastal plain as in the Gulf, but the faunas found in the beds indicate that they should be correlated with the divisions of the Gulf Eocene above referred to.

The insufficient data available from the Miocene and Pliocene formations of the Gulf make it impossible to correlate the deposits of the two areas with any degree of accuracy, although the strata known as Lafayette have been traced along the Piedmont margin to the Gulf district, where the formation was first described.

It is impossible to compare the Pleistocene formations of the Atlantic coastal border with those of the Gulf district, as no adequate differentiation of these deposits has been attempted in the latter area. Whether similar terraces occur facing the coast and bordering the estuaries and streams can not be stated as yet.

The paper was discussed by Bailey Willis.

This paper was followed by the reading of

GEOLOGIC RELATIONS OF THE CRETACEOUS FLORAS OF VIRGINIA AND NORTH CAROLINA

BY EDWARD W. BERRY[1]

[*Abstract*]

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INTRODUCTORY

The Cretaceous of the Atlantic Coastal plain may be readily divided into two series of deposits—an older estuarine series of clays, lignites, conglomerates, and arkosic cross-bedded sands and a younger marine series of mostly glauconitic sands. The older attain their best development in Maryland, while the younger are more differentiated in New Jersey, although they attain a greater thickness in the extreme southern Coastal plain. The older deposits abound in fossil plants, while the younger contain an abundant marine, largely invertebrate, fauna. The transitional beds intercalated between these two series of deposits have consequently a flora more or less closely related to that of the older deposits, while their fauna is more or less closely related to those of succeeding deposits, which facts offer an excellent opportunity for differences of opinion regarding their exact equivalence. These older deposits are found overlapping the eastern border of the Piedmont rocks along the so-called "fall line" from Delaware to Alabama, but are largely covered by the landward transgression of the much later Tertiary deposits, especially in the region from Fredericksburg, Virginia, to Fayetteville, North Carolina, and again in northeastern Georgia.

The Cretaceous deposits of Virginia have been definitely known since the days of Rogers and have been the subject of a voluminous literature. Those of North Carolina have been but recently studied, and are about to be described by Dr L. W. Stephenson, of the United States Geological Survey. The writer collaborated in considerable of the field work, and also had the privilege of studying the fossil plants which were collected. The present brief communication is presented more for the purpose of acquainting geologists with the work in progress than it is to record finished results, in consequence of which a detailed statement is avoided. The three most interesting geologic questions are those of age—that is, correlation, segregation, and paleobotanic features—and in all three categories the present conception differs very materially from those which have gone before.

THE LOWER CRETACEOUS OF VIRGINIA—ITS CORRELATION AND FLORA

These deposits coincide with the beds which Professor Marsh insisted were Jurassic in age and which Professor Ward divided into four formations (James River, Rappahannock, Mount Vernon, and Aquia), and from which

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[1] Introduced by W. B. Clark.

Fontaine and Ward have described or listed about 737 species of fossil plants in 198 genera.

Considering for a moment their areal distribution, we find a practically continuous belt from Alexandria to Fredericksburg. Near Fredericksburg the Eocene is found capping the Cretaceous outcrops, until south of that town the latter are entirely covered as far as the vicinity of Dodson, where a few streams have trenched the Cretaceous beds in a limited area. From Dodson to Richmond they are again buried by both Eocene and Miocene deposits. Between Richmond and Petersburg the James and the Appomattox rivers have cut channels, along which excellent Lower Cretaceous sections are exposed from these towns seaward almost to where the Appomattox enters the James at City Point. Southward from Petersburg to the North Carolina line the Cretaceous is again buried, only showing itself in the stream bed of the Nottaway river.

These deposits are separable into two series, an older and a younger. The older is more or less conglomeritic, with much cross-bedded arkosic sands, containing cobbles and clay balls and lenses of green clay, the latter due to the chloritic schists which contributed to the sediments. These clay lenses and balls contain plants. The younger is similar in character, but more uniform, and was evidently deposited in quieter waters, the sands being often argillaceous enough to be called clays.

The older series is correlated with the Patuxent formation of Maryland because of its similar position with relation to the Piedmont; its practical continuity with that formation in Maryland; its similar lithological character and its identical flora. The European equivalents are, speaking rather broadly, the Wealden or the Neocomian, Urgonien, and perhaps the Aptian. The younger series of deposits is correlated with the Patapsco formation of the Maryland section, of which it is the southern extension, the brownish argillaceous sands of Fort Foote, Maryland, carrying an abundant flora, reappearing across the Potomac at Mount Vernon, White House bluff, Aquia creek, etcetera, exactly similar in character and with an equally abundant and identical flora. The European equivalents of the Patapsco formation are the Gault of England and the Albian of continental Europe, the flora of the latter especially, as described from Portugal by Saporta, having not only the same general facies, but containing a large number of similar and several identical types. Speaking broadly, the Patuxent and Patapsco floras are to be correlated with the Glen Rose flora of the Texan region, the Shasta flora of the Pacific coast, the Kootanie of Montana and Canada, the Lakota of the Black Hills region, and the Kome flora of western Greenland. Exact parallels can not be drawn as yet, although it would seem as if the base of the Kootanie (Morrison) should be placed at a slightly lower level than the base of the Patuxent, and that the Shasta flora should be considered as the flora of the upper unequivocal Cretaceous portion of the Knoxville beds.

The floras of the Patuxent and Patapsco are strikingly different in their entirety, but contain many similar elements, their distinctions resting largely on the comparatively large number of dicotyledonous plants which for the first time are found fossil in the Patapsco formation. Much has been written, both fanciful and otherwise, of the primitive Angiosperms of the Older Potomac. This was due in part to the inability of previous workers to differentiate these two formations when present in the same exposure and the consequent mixing of collections. It was also occasioned by undue specific differentiations proposed and the diagnostic value assigned to undeterminable fragments.

Whereas several hundred species have been described from these beds, there are probably not more than 150 to 250 species capable of recognition. For example, Professor Fontaine describes 10 species of a coniferous genus, *Negeiopsis*, from these deposits. A most careful revision of all the material discloses but three species, in some specimens at least three of the former specific types being shown on a single branch. The same author describes 42 species of the fern genus *Thyrsopteris* from this state. I have repeatedly gone over this material, and while I have not decided just where to draw the lines, there are only two distinct types represented in all the material on which these 42 species were based, their seeming diversity being due to individual variations with all terms of the series present, coupled with the differences due to the position on the fronds from which the particular specimens happened to come, the foliage in question being that of a tree fern with large decompound fronds. These are not exceptional cases, but the same is true of genera like *Podozamites, Cladophlebis, Sequoia, Arthrotaxopsis, Sapindopsis*, etcetera.

THE UPPER CRETACEOUS OF VIRGINIA

No deposits of Upper Cretaceous age have been recognized as outcropping in the Virginia area, although the evidence obtained from deep-well borings in the eastern part of the Coastal plain clearly shows the existence of strata of this age beneath the Eocene.

THE LOWER CRETACEOUS OF NORTH CAROLINA AND ITS CORRELATION

Entering North Carolina, we find the barnacles of the Lower Miocene sea clothing the decayed granites of the Piedmont near Weldon. Eastward from the fall line at this point the Roanoke river has trenched the Cretaceous surface, and characteristic Lower Cretaceous materials are exposed beneath the Miocene in the river bluffs for a score of miles. The next stream which uncovers the Potomac beds is the Tar river, along whose banks low exposures are seen for several miles above and below Tarboro overlain by Later Cretaceous deposits or Miocene, and the same is true of Contentnea creek. To the southward of the Hatteras axis later conditions seem to have been different from those which existed in northern North Carolina and Virginia, and the Lower Cretaceous is present in force in the Upper Cape Fear basin for about 25 miles above and 14 miles below Fayetteville.

The materials are similar to those from Maryland and Virginia. Semilithified arkosic coarse cross-bedded sands more or less argillaceous predominate. This formation has been named the Cape Fear formation by L. W. Stephenson.

This formation is to be correlated with the Patuxent formation of Maryland and Virginia, since its lithological character is the same, its position on the eastern margin of the Piedmont is the same, and it is overlain unconformably by Upper Cretaceous deposits which correspond roughly to the Magothy and Matawan formations of the Maryland region. The Patapsco formation which is present in the northern Virginia area shows every evidence of pinching out north of the James river. Unfortunately no fossil plants are known from the Cape Fear formation. These are to be expected locally in clay lenses after the manner of their occurrence to the northward, where they are also extremely local. The attitude of the North Carolina Coastal plain, with its almost continuous mantle of Tertiary or surficial deposits, renders exposures comparatively scarce, and this factor, combined with the more uniformly unfavorable conditions for fossilization, has thus far rendered our search for fossils unsuccessful.

THE UPPER CRETACEOUS OF NORTH CAROLINA

The only Upper Cretaceous formation with which I am concerned is the basal one in this region which marks the transition to the typically marine deposits of the Peedee formation. It has been named the Black Creek formation by Earle Sloan because of the exposures along Black creek in South Carolina.

The most northern outcrops of this formation are found in the banks of the Tar river in the vicinity of Tarboro, where they are strikingly unconformable on the Cape Fear formation. Going southward, they are again seen along the Neuse river for a distance of about 20 miles from Blackmans bluff to Goldsboro, and likewise often seen to be unconformably underlain by Cape Fear deposits.

Similar exposures are met with in force along the Black river for a distance of about 30 miles. It is along the Cape Fear river, however, that the section is most complete. In this region these beds are found from Rockfish creek near Hope mills, which is a few miles west of Fayetteville to Donohue Creek landing, a distance by the river of something like 65 miles. To the landward they rest with marked unconformity on the Cape Fear formation. Coastward they disappear beneath the typical green sand of the Peedee, which overlies them conformably.

The materials are largely laminated sands and lignitic clays. The sands are micaceous and iron stained and of a loose sugary character, often cross-bedded. The usually dark clays are very lignitic and usually thinly laminated. Local lenses of brownish clay carry an abundant flora, which is also present in less abundance in the dark laminated clays. Amber in small globules is uniformly distributed. Toward the top of the formation glauconite makes its appearance in pockets and lenses, accompanied by teredo-bored logs, sharks' teeth, and marine invertebrates.

About 75 species of fossil plants have been collected from this horizon in North Carolina. These are distributed among 24 localities, the bulk, however, coming from a single outcrop, that at Court House bluff on the Cape Fear river, about 39 miles below Fayetteville and 76 miles above Wilmington. The Black Creek formation is tentatively correlated with the Upper Tuscaloosa and Eutaw formations of Alabama, the Middendorf and Black Creek formations of South Carolina, the Magothy and Matawan formations of New Jersey, Delaware, and Maryland, the Woodbine formation of Texas, and the Dakota group of the western interior. It finds its parallel in the Atane and Patoot beds of Greenland. It is difficult to be more exact at the present time, but it seems probable that the Black creek more nearly represents the Magothy-Matawan formations of the more northern Coastal plain rather than the Raritan. Judged by European standards, it seems to be late Cenomanian in age. Were the Turonian of Europe indicated anywhere along our Coastal plain by paleozoological evidence, or were the floras of the European Turonian extensive enough for accurate comparisons, I would incline toward correlating the Black Creek formation as well as the Magothy formation with the Turonian. The most abundant plant in the Black Creek formation, a new species of *Araucaria*, has its nearest relative in a similar species from the Magothy formation at Cliffwood, New Jersey, and another from the Turonian of France (near Toulon). Another of the common Black Creek plants, a *Pistia*, while not found in the Magothy formation, occurs in Greenland (Atane).

There is a great resemblance between the flora of the Black Creek formation and those of various European formations which are commonly considered as Cenomanian in age, such as those of Portugal (Saporta); Niederschœna, Saxony (Ettingshausen); Moletein, Moravia (Heer); Bohemia (Velenovsky).

The Society then listened in general session to the reading of the following papers:

PALEOGEOGRAPHY OF NORTH AMERICA

BY CHARLES SCHUCHERT

The paper has been published as pages 427-606 of this volume.

Then was read

REVISION OF THE PALEOZOIC SYSTEMS IN NORTH AMERICA

BY E. O. ULRICH

This paper may be published in volume 21 of the Bulletin.

Doctor Ulrich's paper was interrupted by adjournment at 5.45 P. M., and the reading was finished on Thursday. It was discussed by A. W. Grabau.

At 7 o'clock Wednesday evening the Fellows and their friends, to the number of 133, gathered at the hotel Rennert for the annual dinner of the Society. President Calvin presided, and, after dinner, remarks were made by him and Messrs Gilbert, Penck, W. B. Clark, G. O. Smith, Brock, Chamberlin, Hovey, Gulliver, Van Hise, Emerson, and Stevenson.

The Society convened again at 9.45 o'clock Thursday morning, President Calvin being chairman, and, after hearing sundry announcements, listened to the reading by the Secretary of the following

REPORT OF THE COMMITTEE ON EARTHQUAKE AND VOLCANO OBSERVATIONS

Acknowledgments have been received from the governors of the Leeward islands, of Hawaii, of Jamaica, and of Saint Thomas, from the chairman of the Isthmian Canal Commission, and from the secretaries of the Smithsonian Institution and of the committee on seismology of the American Association for the Advancement of Science.

Hon. W. F. Frear, governor of the Hawaiian islands, writes:

"Hawaii is an important point for observations of this kind, but how much can be done in this direction is a question. I shall be glad to give what encouragement I can in this matter. The federal government now has a magnetic observatory here, which also contains a seismograph."

William Johnstone, Esq., colonial secretary of Jamaica, writes:

"In reply I am to state for the information of the Society that the Weather Service of Jamaica has already in use two seismometers in this island, one at Kingston and one at Chapelton, about the center of the island, and that there are now being constructed here about a dozen seismometers on an improved principle."

Colonel George W. Goethals, chairman and chief engineer of the Isthmian Canal Commission, writes:

"We have now at Ancon, Canal zone, an observatory equipped with a complete assortment of modern, self-recording meteorological instruments, *i. e.*, barograph, air and water thermograph, hydrograph, barograph à poid, triple register (wind direction and velocity, rainfall and sunshine), and the standard instruments necessary properly to correct their records. We expect shortly to erect two horizontal pendulum Bosch-Omori seismographs—one a hundred-kilogram pendulum instrument (tromometer), which will enable us to obtain registered records on smoked paper of all movements of a telluric nature, either seismic or otherwise, near or distant, and also the variations of the vertical line. The magnification is 100, and the period of oscillation of the tromometer can be extended to forty seconds. Attached to this instrument is an air-damping apparatus, by which the oscillations may be reduced, or even rendered aperiodical. Owing to its sensitiveness, this instrument is well adapted to the registration of earth tremors, pulsatory oscillations, and comparatively quick period earthquake vibrations.

"The proposed new equipment, therefore, will be such as to enable us to make observations in connection with earthquakes, whether of a tectonic nature or produced by volcanic action, as well as of other physical phenomena, such as earth tremors and pulsations, which may, as premonitory signs, have a bearing on the prediction of earthquakes. We are also prepared to study the relations that may exist between seismic disturbances, pressure, and temperature.

"While we can not make our studies cover the entire field of seismology, we believe our observations will be of considerable utility in the work that the Geological Society of America has undertaken."

The chairman of your committee has to report for his own district that, through the efforts of Professor J. B. Woodworth, Harvard University has installed a seismograph which is in active operation, and that money has been given by citizens of Boston whereby another Bosch-Omori instrument has been secured, and plans and drawings are now under consideration with a view to the building of a geophysical observatory near Boston, which will be under the direction of the department of geology of the Massachusetts Institute of Technology.

T. A. Jaggar, Jr., *Chairman.*

The Secretary reported from the Council the constitution of W. B. Clark, H. E. Gregory, C. W. Hayes, J. M. Clarke, and E. O. Hovey a committee to confer as to details with a Committee of Organization, which had been chosen by certain paleontologists desiring to form a Paleontological Society as a section of and in close affiliation with the Geological Society of America, the Council heartily commending the project.

On motion, the action of the Council was endorsed and the committee given authority to act for the Society.

The Society then divided into two sections, and the following papers were presented under the chairmanship of President Calvin:

CLASSIFICATION OF CRYSTALS BASED UPON SEVEN FUNDAMENTAL TYPES OF SYMMETRY

BY CHARLES K. SWARTZ

This paper has been published as pages 369-398 of this volume.

The paper was discussed by W. H. Hobbs, E. H. Kraus, W. N. Rice, and H. B. Patton.

The following paper was read by title:

USE OF "OPHITIC" AND RELATED TERMS IN PETROGRAPHY[1]

BY ALEXANDER N. WINCHELL

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INTRODUCTION

For thirty years the term "ophitic" has been used in petrographic descriptions to describe certain textures found in basic igneous rocks, especially diabases. It is today used more or less currently wherever such rocks are studied microscopically. And it may be perhaps in some measure due to this widespread use of the term by many authors that a difference of usage has developed. This difference of usage is nowhere more clearly expressed than by Lane,[2] who says:

> "It is to be noted that I use the term ophite, ophitic, as I have heretofore—that is, in accordance with its original definition and in a narrower sense than it sometimes has been used.
>
> "Michel Lévy is responsible for the introduction of the term into petrography, and we take the definition from his 'Structures et Classification des Roches Éruptives,' page 26:
>
> > "'When[3] the last element consolidated is a bisilicate (generally pyroxenic), its outlines, without their own external contours, are interlarded with other crystals; those of feldspar are notably elongated parallel to the intersection of 001 with 010, or are flattened parallel to 010, and the aggregate assumes a characteristic appearance which I described and illustrated as early as 1877 under the name of ophitic structure.'

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[1] Manuscript received by the Secretary of the Society December 26, 1908.

[2] Geological Survey of Michigan, vol. vi, part 1, 1898, p. 227.

[3] "Quand le dernier élément consolidé est un bisilicate (généralement pyroxénique), ses plages, sans contours extérieurs propres, sont lardées de cristaux plus anciens; ceux de feldspath notamment s'allongent suivant l'arête pg^1 (001) (010), ou s'aplatissent suivant g^1 (010), et l'ensemble prend une apparence caractéristique que j'ai décrite et déssinée dès 1877 sous le nom de structure ophitique."

"In this definition there are three points: first, that the pyroxene component is last consolidated; second, that it occurs in areas which are larded, as meat is larded for cooking, with streaks of older crystals; and thirdly, that these crystals are much flattened or elongated. Vélain, for example, in his Conférences de Petrographie (page 59), speaks of the ophitic texture as characterized by the elongation of the feldspathic element, and its distribution through the areas of the ferruginous element (pyroxene). But it has often happened that only the first or third point has been taken to be essential to the definition. Lapparent (Géologie, 1883, page 630) alludes to the tendency of the feldspar to form elongate crystals as characteristic of the ophites, but his figures and descriptions show the areas of pyroxene in which they are embedded. We find that in their experiments on the reproduction of rocks, Fouqué and Lévy apply the term ophite, not to all rocks having elongate feldspar or xenomorphic pyroxene, but to those only that have the structure above described."

Present Usage

Inasmuch as prominent petrographers are therefore not in accord as to the meaning of the word, it is desirable to determine, if possible, what meaning was given to it by its author, and what modifications of that meaning, if any, are justified, either by the usage of the author of the term or by any other means. At the same time its relation to other terms of similar meaning may be advantageously brought to light.

The word has been used in its narrow sense by Lane,[4] Harker,[5] Wadsworth,[6] Judd,[7] Rutley,[8] and Teall.[9]

Rosenbusch,[10] in 1887, made it a synonym of his diabasic (diabasische-körnig) structure in some statements, but in others he uses it in the narrower sense. In 1901 he used ophitic as synonymous with doloritic, diabasic, and divergentstrahlig. If less pyroxene and some residual glass were present he called the structure intersertal. Kemp[11] used ophitic in the wider sense in the first edition of his well known "Handbook of Rocks," but in later editions he changed to the narrower meaning. Lacroix[12] defined the term in the narrow sense in 1896, but in 1899 he used it in the wider sense. Among others who have used the word in the broader sense are Zirkel,[13] Williams,[14] Loewinson-Lessing,[15] Rinne,[16] Lawson,[17] Clements.[18]

Original Definition

As mentioned by Michel Lévy in the definition quoted by Lane, the former defined the structure characteristic of ophites as early as 1877, in terms not identical with those quoted by Lane; the original definition is as follows:[19]

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[4] Loc. cit. See also Bulletin of the Geological Society of America, vol. 18, 1906, p. 648.

[5] Petrology for students, 1897, p. 126.

[6] Geological and Natural History Survey of Minnesota, Bulletin 2, 1887, p. 107.

[7] Quarterly Journal of the Geological Society, 1885, p. 360; 1886, p. 68.

[8] Granites and Greenstones, 1894, p. 14.

[9] British Petrography, 1888, p. 135.

[10] Mikr. Phys., 2 auflage, 1887, II, pp. 190, 191. Elem. Gest., 2 auflage, 1901, p. 326.

[11] Handbook of rocks, 2d ed., 1900, pp. 44, 158; 3d ed., 1906, pp. 71, 210.

[12] Minér. France, II, 1896, p. 34. Le Gabbro du Pallet, 1899, p. 28.

[13] Lehrb. Petr., 1893, I, p. 689.

[14] U. S. Geological Survey, Bulletin 62, 1890, p. 196. American Journal of Science, vol. xliv, 1892, pp. 482, 492.

[15] Geological Survey of Michigan, vol. vi, part 1, p. 227, footnote.

[16] Gesteinskunde, 1901, p. 87.

[17] Geological Survey of Canada, Annual Report, vol. iii, 1887, p. 58F.

[18] U. S. Geological Survey, Monograph xxxvi, 1899, p. 200.

> "The ophites are characterized by the constant presence of diallage or of augite altering to diallage; this bisilicate molds the elongated crystals of triclinic feldspar, generally clustered in groups, which do not deserve the name of microlites in spite of their elongation and rather small dimensions; this aggregate habitually encloses old crystals of titanic iron. It is to this characteristic grouping of feldspar of recent consolidation and of diallage still more recent that the ophites owe their structure intermediate between the granulitic and the microlitic structure, but actually more closely related to the former."

There is in this original definition no statement that a single pyroxene must inclose several feldspar crystals; there is, on the contrary, the simple statement that "it is to this characteristic grouping of feldspar of recent consolidation and of diallage still more recent that the ophites owe their structure." The essential thing is simply that the feldspars formed *before* the pyroxene. According to the original definition, therefore, the word ophitic has a broad meaning, applying to all cases where the plagioclase crystals formed before the pyroxene, and is not to be confined to those instances where the pyroxene occurs in large anhedra inclosing the feldspar in poikilitic fashion.

USAGE OF MICHEL LÉVY

Proceeding now to the usage of the author of the term, we find that in the great Minéralogie Micrographique of Fouqué and Michel Lévy, published in 1879, the term is defined (page 153) as follows:[20] "The ophitic texture in which the crystals of feldspar are elongated parallel to one of the sides of the face 010, forming thus a type grading toward the microlitic rocks." It would be difficult to state more clearly a definition depending not upon two or three conditions, but upon one alone, and that one is here stated to be the elongation of the feldspar. Such elongation necessarily involves the crystallization of the feldspar before the final solidification of the rock. In the same work the structure is illustrated by several photomicrographs, which show that the term is applied to rocks in which pyroxene (or a related mineral) crystallized after feldspar; they also show (plate xxxvi, figure 2) that the pyroxene is not necessarily in large areas, but may be in small grains ("augite en microlithes globuleux"), no one of them large enough to inclose the long lath-shaped crystals of plagioclase. When Michel Lévy wrote his "Structure et Classification des Roches Éruptives," in 1889, he referred directly to the original definition quoted above. It is therefore clear that the statement that the pyroxene masses are interlarded with older crystals, especially elongated feldspar ("ses plages, sans contours extérieurs propres, sont lardés de cristaux plus anciens; ceux de feldspaths notamment s'allongent"), must be taken to include not only the texture, which is poikilitic, but also the structure, in which the fine granular pyroxene masses are penetrated by lath-shaped plagioclase crystals of indefinite orientation. In other words, it includes all cases in which the elongated plagioclase crystallized before the pyroxene (or other ferromagnesian) constituent of the rock.

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[19] Bull. Société Géologique de France, vol. vi, 1878, p. 158. Read December, 1877. "Les ophites sont caractérisées par la présence constante du diallage ou d'un augite passant au diallage; ce bisilicate moule des cristaux allongés de feldspath triclinique, généralement groupés entre eux, et qui ne meritent pas le nom de microlithes malgré leur allongement et leur dimensions assez exiguës; le tout englobe habituellement des cristaux anciens de fer titané. C'est à ce groupement caractéristique de feldspath de consolidation récente et de diallage plus récente encore que les ophites doivent leur structure intermédiaire entre la structure granulitique et la structure microlitique, mais se rattachant en réalité plus intimement à la première."

[20] "La structure ophitique, dans laquelle les cristaux de feldspath s'allongent suivant l'un dés côtés de la face g^1 (010), formant ainsi un type de passage vers les roches microlitiques."

At the time that Fouqué and Michel Lévy[21] attempted to reproduce the ophitic texture artificially in 1881 they defined it as follows:[22] "As is well known, these rocks are characterized by the development of microlites of triclinic feldspar, molded and often inclosed by extensive areas of pyroxene." Here the large areas of pyroxene are included in the definition, perhaps because this type of the ophitic texture was the one actually obtained experimentally. But the definition can not refer to a variety of the poikilitic texture alone, since these areas either inclose *or* mold themselves about the earlier feldspar crystals. Furthermore, the text states that the "large" areas of pyroxene had an average diameter less than twice the length of the feldspar crystals.

When Fouqué and Michel Lévy reported the discovery of a mineral erroneously called diamond in South African rocks, they described the inclosing rocks[23] as follows: "Their type of texture, very uniform, is ophitic; they are rocks entirely crystalline, in which the feldspathic element is elongated parallel to the axis *a*, while all the other minerals of later consolidation are granulitic." Here the important characteristic of the texture is clearly stated to be the early crystallization of the feldspar with resultant automorphic elongation.

Related Terms

So far as the writer is aware, of all the terms that have been used as more or less exactly synonymous with ophitic, Zirkel's intersertal[24] is the only one that has the right of priority as compared with Michel Lévy's term. Zirkel defined the intersertal structure as present in "Feldspar basalts consisting of larger crystals and an apparently amorphous and not individualized matrix, pressed and squeezed into the spaces between the divergent sections of the phenocrysts, and so reduced in amount that it does not at all play the part of a true groundmass." Of this structure he names three varieties: First, that in which the groundmass (zwischengeklemmte Masse) is wholly of glass; second, with the groundmass "half glassy" by the appearance of granules in it; third, with the groundmass so abundantly supplied with needles and granules that only a little glass remains. According to its original definition, therefore, the intersertal structure requires large euhedral crystals in divergent groups in a groundmass which contains more or less glass. In this form it would seem to apply very well to certain coarsely spherulitic textures rather than to the ophitic texture. It may be said that the later usage of various writers, notably Rosenbusch and Zirkel, gives the word a somewhat different meaning, making it apply to a texture in which rudely divergent *feldspar* crystals occur in a base containing more or less glass. In this sense the word is later than ophitic, and therefore can be regarded as nothing more than a variety of the latter, in which glass is present in the groundmass ("mesostasis").

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[21] Bull. Soc. Min. Fr., vol. iv, 1881, p. 277.

[22] "On sait que ces roches sont caractèrisées par le developpement de microlithes de feldspath tricliniques, moulés et souvent englobés par des plages étendues de pyroxène."

[23] C. R., LXXXIX, 1879, p. 1125: "Leur type de structure très uniforme, est ophitique; ce sont des roches entièrement cristallisées, dans lesquelles l'élément feldspathique est allongé suivant l'arête pg^1, tandis que les autres minéraux de seconde consolidation sont granulitiques."

[24] *Basaltgesteine,* 1870, p. 111: "Feldspathbasalte, bestehend aus grössern Krystallen und einer zwischen die divergirenden Durchschnitte derselben gedrängten und geklemmten, als solche amorphen und nicht individualisirten Masse, welche an Quantität zurücktretend, keineswegs die Rolle einer eigenlichen Grundmasse spielt."

Other terms, which are somewhat related to ophitic in their meaning, include luster-mottled, "divergent-strahlig-körnig," diabasic, doleritic, radiolitic, and poikilitic. These terms are all of later origin than ophitic. Their history may be summarized as follows:

Pumpelly[25] proposed the term luster-mottlings (whence, of course, luster-mottled) only a month later than the date of Michel Lévy's article on ophites and their structure. The term was quite fully described and applied to those ophitic textures which are also poikilitic. It would probably be more commonly used if it were less cumbrous. It is an exact synonym of ophitic in the narrow sense advocated by Lane.

Lossen[26] is the author of the awkwardly long expression "divergent-strahlig-körnig." He defined it in 1880 thus:

> "Especially the diabases of the horizon under discussion are accustomed to possess dominantly a more or less distinct divergent radial-granular, not pure-granular, structure, in which the lath-shaped development of the plagioclase individuals dominates the fabric, so much, indeed, that the rest of the mineral particles are arranged between the meshes of the feldspar laths."

The essential thing in this definition is the dominance of lath-shaped plagioclase crystals in the texture. The term is therefore a synonym of ophitic.

Lœwinson-Lessing,[27] in 1887, suggested the shorter term radiolitic (radiolitische) as a substitute for Lossen's term.

In the same year Rosenbusch[28] proposed the term diabasic (diabasisch-körnig) for the ophitic texture. His description of this texture was as follows:

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[25] Proceedings of the American Academy, vol. xiii, 1878, p. 260.

[26] Jahrbuch k. pr. geologische Landesanst, 1880, p. 8: "Speciell die Diabase des im Rede stehenden Horizontes pflegen vorwiegend eine mehr minder deutlich divergent-strahlige-körnige, nicht rein körnige Structur zu besitzen, wobei die leistenförmige Ausbildung der Plagioklas-Individuen das Gefüge beherrscht, so zwar, dass die übrigen Mineralgemengtheile zwischen das Maschenwerk dieser Feldspathleisten eingeordnet sind."

[27] T. M. P. M., vol. ix, 1887, p. 70.

[28] Mikroskopische Physiographie, 2 auflage, II, 1887, p. 190: "Die Structurformen der Diabasgesteine zeigen trotz manchen, meist localen und wenig verbreiten Eigenthümlichkeiten eine gewisse Monotonie. Betrachtet man zunächst die Structur der Diabase nach ihren Hauptcharakter, so gehört dieselbe mit Entschiedenheit zu den hypidiomorph körnigen; im Vergleich mit den typischen stockförmigen Tiefengesteinen stellen sich jedoch eine Anzahl abweichender Verhältnisse hereaus, denen zufolge fast alle Forscher der Diabasstructur eine Sonderstellung einräumen und sie als 'ophitisch' (Fouqué und Michel-Lévy), 'divergent-strahlig-körnig' (Lossen), oder diabasisch-körnig bezeichnen. Diese Eigenthümlichkeiten lassen sich auf zwei Ursachen zurückführen; die meistens sehr ausgesprochene Leistform der Plagioklase und die frühere oder doch nicht ausgesprochenen spätere Krystallisation derselben aus dem Magma im Vergleich zu den pyroxenischen Gemengtheilen."

> "The structures of diabase rocks, in spite of many chiefly local and not widespread peculiarities, show a certain monotony. If one considers first the structure of the diabases according to its chief characteristic it belongs with certainty to the hypidiomorphic granular type; in comparison with typical [bathylith- or] stock-shaped abyssal rocks they present, however, a number of differing relationships to which consequently nearly all students of the diabase structure have granted a separate designation, and have named 'ophitic' (Fouqué and Michel Lévy), 'divergent-strahlig-körnig' (Lossen), or diabasic-granular. These peculiarities may be traced back to two causes; the usually very distinctly lath-like shape of the plagioclases, and the earlier, or at least not distinctly later, crystallization of the same from the magma in comparison with the pyroxenic constituent."

In 1901 Rosenbusch[29] used ophitic chiefly in the narrow sense, and added another synonym (doleritic) to the word in this sense. He also used intersertal as descriptive of the texture of a rock containing little pyroxene and some glass. In 1886 Williams[30] proposed the term poikilitic (first spelled poicilitic, then pœcilitic, and finally, in 1893, poikilitic) to designate a rock structure in which one mineral in large individuals envelopes smaller individuals of other minerals which are not regularly arranged. It differs from ophitic in the narrow sense above defined in being applicable irrespective of the nature of the inclosed or of the inclosing mineral, and also in being applicable whether the inclosed mineral have definite form or not. But as applied to one mineral inclosing rounded individuals of other minerals, it should not be used, since other terms have priority, notably "globulaire" of Michel Lévy,[31] for the English equivalent of which the writer would suggest that globulitic is to be preferred to globular. The term was first applied to rounded quartz grains in a glassy base; later its meaning was extended to apply to rounded grains inclosed by other minerals. For this latter sense Salomon's contact[32] structure and Bayley's granulitic[33] structure are synonyms, although they are also applicable to a finely granular structure made up almost entirely of small rounded grains, a grain of one mineral sometimes inclosing one or more of another mineral.

SUMMARY

To summarize: a texture exists quite commonly in rather basic igneous rocks which has received many names. It is a texture characterized by the fact that the plagioclase feldspar, contrary to the usual order of crystallization, consolidated in lath-shaped forms before the ferro-magnesian constituents. This texture was defined and illustrated by Michel Lévy in 1877, when he declared it was characteristic of the group of rocks he called ophites. Since then the term ophitic has come into wide usage, but it is now used with either one of two different meanings. Some writers follow the original definition and the practice of its author in applying the term to all rocks having plagioclase in lath-shaped crystals of early formation. Others, apparently misunderstanding a much later description of the texture,[34] confine the term to those rocks whose lath-shaped feldspars are poikilitically inclosed by large anhedra of pyroxene. It seems evident from both the original definition and from the usage of the author that, while such a poikilitic arrangement is included, it is not essential to the texture; and it appears that pyroxene itself is equally non-essential according to the usage of the author, since he says the last mineral to crystallize is *generally* pyroxene, and, moreover, applies the term ophitic to a rock from Greenland[35] in which the pyroxene is replaced by native iron.

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[29] Elem. Gest., 2 auflage, 1901, p. 326.

[30] American Journal of Science, vol. xxxi, 1886, p. 30; xxxiii, 1887, p. 139. The term Poikilitic was proposed by Conybeare to designate the "New Red Sandstone," or Permian and Triassic (together) of England. It was used also by De La Beche, John Phillips, and H. B. Woodward in the same sense. T. H. Huxley (Geological Magazine, vol. vi, 1869, p. 89) suggested that it be used to refer to terrestrial deposits of Permian and Triassic age, and he thought such deposits in some cases indicated continuous fauna rather than changing fauna. But the use of the term in this sense is now wholly obsolete, and, even if it should be revived, it could cause no confusion with the use proposed by Williams. See also: Journal of Geology, vol. i, 1893, p. 176.

[31] Bull. Soc. Geol. Fr., vol. iii, 1875, p. 199.

[32] Z. d. d. geol. Gesell., vol. xlii, 1890, pp. 487, 511.

[33] Journal of Geology, vol. iii, 1895, p. 1.

It appears, therefore, that the term ophitic should be used in the broad sense already defined, for which usage it has clear priority over all other terms. Furthermore, if a rock with ophitic texture has glass in the groundmass the texture may properly be called intersertal, which thus designates a variety of the ophitic texture. It appears also that the terms divergent-strahlig-körnig of Lossen, radiolitic of Lœwinson-Lessing, and diabasic and doleritic of Rosenbusch are needless synonyms of ophitic. Finally, it may be suggested that if luster-mottled be considered too cumbrous a term to describe a texture which is at once ophitic and poikilitic, it might well be called poikilophitic.

Then was read

CHEMICAL COMPOSITION AS A CRITERION IN IDENTIFYING METAMORPHOSED SEDIMENTS

BY EDSON S. BASTIN [1]

[*Abstract.*]

This paper called attention to the small number of definite statements, even of a qualitative character, in geological literature, as to the nature and value of chemical criteria in distinguishing schists of sedimentary from those of igneous origin. Quantitative statements are wholly wanting.

By compiling a large number of analyses of pelitic sediments the writer showed the nature of the chemical changes involved in their metamorphism. He then proceeded to contrast the composition of the pelitic schists and gneisses with that of their allies among igneous rocks. The calculation of the "norm" of a schist and its classification, according to the quantitative system of Cross, Iddings, Pirsson, and Washington, was pointed out as a convenient method for making such comparisons.

These statistical studies brought out not only the character of the chemical criteria which may be used, but gave a quantitative measure of their value. The paper concluded with the application of these criteria to certain selected schist and gneiss analyses.

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[34] A. Michel Lévy: Structures et Classification des Roches Éruptives, Paris, 1889, p. 26.

[35] C. R., vol. xcii, 1881, p. 891, and Ann. Ch. Phys., vol. xvi, 1879, p. 505.

[1] Introduced by G. O. Smith.

The discussion on this paper was participated in by B. K. Emerson, W. S. Bayley, F. D. Adams, and E. S. Bastin.

After this the following paper was read by title:

PETROLOGY OF THE SOUTH CAROLINA GRANITES (QUARTZ MONZONITES)

BY THOMAS LEONARD WATSON

The next two papers, being on related topics, were presented orally in succession:

TERTIARY DRAINAGE PROBLEMS OF EASTERN NORTH AMERICA

BY AMADEUS W. GRABAU

[*Abstract*]

The Laurentian river of Spencer carried the collected drainage of the Great lakes through Ontario valley and out by the way of the present Saint Lawrence. The Finger Lake valleys and the Genesee are regarded as made by tributary northward flowing streams. Fairchild regards these as northward flowing tributaries of a (possibly) westward flowing river in the Ontario valley. The author has in the past shown that a normal sequential drainage system, the general direction of which was northward, and in which the minor streams were beheaded by the master, accounted for all the topographic features of the region in question. Subsequent blocking of some of the channels by drift and deepening of others by ice, and a general depression of the country to the northeast, has produced the present drainage system. The problems were discussed in the light of accumulated facts.

DRAINAGE EVOLUTION IN CENTRAL NEW YORK

BY H. L. FAIRCHILD

[*Abstract*]

The paper aims to assist in the elucidation of the complex physiography of the western helf of New York state. Three maps represent graphically the general evolution of the drainage and the interference by glacier invasion of the normal stream development.

The first map shows the existing valleys which are, apparently, an inheritance from the ancient drainage, southwestward, across the uplifted peneplain. These inherited valleys fall into three classes: (*a*) those in which the present flow is the same as the primitive, (*b*) those which are abandoned or left as "hanging" valleys, and (*c*) those in which the stream flow has been reversed. A remarkable parallelism is exhibited by these valleys, which, except in the district of the Delaware and upper Susquehanna, are transverse to the present master streams. At Lanesboro the primitive Susquehanna continued directly south, instead of bending northwest as now, and then occupied in Pennsylvania the Tunkhannock valley. Other valleys in northern Pennsylvania represent the continuation of the southwestward flow in central New York.

The second map exhibits the hypothetical Tertiary drainage. During later Tertiary time all the drainage of the west half of the state was diverted westward (subsequent) and northward (obsequent) into a great trunk stream that occupied the Ontario and Erie valleys and probably drained westward into the Mississippi basin. The cause of this radical reversion of flow was the great thickness of non-resistant rocks in the Ontario district. In the vertical series of strata between the Trenton and the Portage, on the Cayuga meridian, are 5,150 feet of rock, of which 4,500 feet are weak shales, 350 feet limestone, and 250 feet sandstone.

The pre-Glacial divide was far south in Pennsylvania. The Allegheny system poured north through the lower Cattaraugus valley. The upper Genesee was tributary to the broad Dansville-Avon river, which almost certainly had its northward course through the Irondequoit valley. The Susquehanna turned west from the site of Lanesboro and Susquehanna villages along the strike of the Chemung strata (which were less resistant than the overlying Catskill), past the sites of Binghamton, Owego, and Waverly, and then curved north through the sites of Elmira and Horseheads and occupied the Seneca valley. The Chemung was the principal tributary from the west, as today, but it passed north of Elmira instead of south, where it now lies in a post-Glacial cut.

The Delaware and the upper tributaries of the Susquehanna were not diverted from their southwest courses.

Along the Ontario lowland the Tertiary channels are almost entirely destroyed or obscured by drift, but the valleys of Irondequoit, Sodus, Little Sodus, and Fairhaven are trenches across the Niagara-Medina scarp, which probably represent the northward pre-Glacial flow. Today only two large streams pass across this rock ridge, the Genesee and Oswego, both in new channels. It seems probable that along the belt of Salina outcrop the pre-Glacial tributary streams flowed east or west as they do today.

It is suggested that the "oversteepened" walls of the bottom sections of the Finger Lakes valleys were produced by the rapid down-cutting of the streams during the Tertiary uplift.

The third map shows the principal stream flow as compelled by the ice-sheets. A few strong south-leading valleys were enlarged or newly cut by the concentrated glacial waters, and the Allegheny and Susquehanna systems were turned to the south. In order from west to east the glacially developed valleys are Cassedaga, Conewango, Ischua, Canisteo, Cohocton, Cayuta, Cattatonk, Tioughnioga. These southeastward drainage lines, transverse to the primitive flow, were carved from numerous, short, subsequent valleys by the stream flow forced to the southward by the ice-damming. Such flow was effective during the advance of the ice-sheet, but stronger during the waning of the ice, and probably more than one ice invasion has been concerned.

On the Ontario lowland the forced drainage was west or east, alongside the ice margin. In the Erie basin the later flow was all westward past the ice front. In the Mohawk valley the drainage between Little falls and Rome was turned from west to east.

The water-parting which in pre-Glacial time lay in Pennsylvania has been so changed by glacial flow that it now lies close to the Finger lakes.

Between the two or more ice invasions lang epochs of warm climate probably permitted some development of valleys, which would be more or less buried by subsequent glaciation. This interglacial work is the most elusive or indeterminate element in the large problem. The last map shows only the final drainage as it has been left by the later Wisconsin ice sheet. In detailed or local study the buried and discordant valleys must be considered.

Nearly all the valleys of central and western New York may be grouped into three classes according to their direction: (1) Those with southwestward direction, which seem to be mainly inherited from the ancient drainage across the uplifting plain. (2) Those leading northward (northeastward in the Erie basin), developed by subsequent flow toward the great master stream in the axis of the Ontario-Erie valley. (3) Those leading southeastward, produced by glacial waters forced toward southern escape.

These papers were discussed together by A. W. Grabau, J. W. Spencer, F. Carney, A. P. Brigham, G. F. Wright, F. B. Taylor, A. P. Coleman, and H. L. Fairchild.

At 12.40 o'clock the Society adjourned for luncheon, meeting again at 2.05 o'clock to continue the reading of papers. President Calvin occupied the chair. The first two papers were read by title. They were

SOME PHYSIOGRAPHIC FEATURES OF THE SHAWANGUNK MOUNTAINS

BY GEORGE BURBANK SHATTUCK

NANTUCKET SHORELINES, III

BY F. P. GULLIVER

Then was presented orally

NANTUCKET SHORELINES, IV

BY F. P. GULLIVER

[*Abstract*]

The strong north and northeast storms of the past fall have closed the Haulover, and the tombolo from Wauwinet to Coskata was completed on November 12, 1908. Some old maps have been studied with reference to the former eastward extension of the oldland at Wauwinet, Coskata, and Folger islands. The changes on Great point since 1896 were compared with previous conditions and with what may be expected in the future. The shoals between Nantucket and Cape Cod and between Nantucket and Marthas Vineyard and the Hyannis shore are considered as attempts of the sea to build tombolos.

After this was presented orally

NOTE ON STRIATIONS, U-SHAPED VALLEYS, AND HANGING VALLEYS PRODUCED BY OTHER THAN GLACIAL ACTION

BY EDMUND OTIS HOVEY

This paper has been published as pages 409-416 of this volume.

The paper was discussed by A. Penck.

Then was read by title

HISTORICAL NOTES ON EARLY STATE SURVEYS

BY GEORGE P. MERRILL

The next paper read was

IRON ORES OF MARYLAND

BY JOSEPH T. SINGEWALD, JR[1]

[*Abstract*]

This paper presents a brief summary of the results of an investigation carried on during the past season on the iron ores of Maryland under the auspices of the Maryland Geological Survey. Four classes of ore were recognized—limonite, hematite, magnetite, and siderite. The paper presented embraced a discussion of the character and chemical composition of each of these ores, the localities in which the deposits occur, and also their geologic and stratigraphic relations.

After this was presented orally

SHORTAGE OF COAL IN THE NORTHERN APPALACHIAN COAL FIELD

BY I. C. WHITE

This paper has been published as pages 333-340 of this volume.

The next paper was read by title.

GLACIAL CHARACTER OF THE YOSEMITE VALLEY

BY FRANÇOIS MATTHES[1]

Then was presented orally

THE MILLS MORAINE WITH SOME DISCUSSION OF THE GLACIAL DRAINAGE OF THE LONGS PEAK (COLORADO) DISTRICT

BY EDWARD ORTON, JR[2]

This paper was discussed by W. T. Lee.

The next paper read was

QUARTZ AS A GEOLOGIC THERMOMETER

BY FRED E. WRIGHT AND E. S. LARSEN

[*Abstract*]

Observations by Le Chatelier and Mallard in 1889-1890 proved that at about 570 degrees quartz crystals undergo a reversible change, the expansion-coefficient, birefringence, and circular polarization all changing abruptly. O. Mügge (*Neues Jahrbuch, Festband*, 1907, 181-196) has recently considered the problem again in detail, and by means of etch figures combined with crystallographic behavior on heating found that below the inversion point quartz crystallizes in the trapezohedral-tetartohedral division of the hexagonal system, while above 570 degrees it is trapezohedral-hemihedral. The high form is very similar to the low form, and differs chiefly in the fact of its common planes of symmetry. A plate formed above 570 degrees is trapezohedral-hemihedral, but on cooling it changes to the trapezohedral-tetartohedral division, thereby losing its common planes of symmetry, which may then become twinning planes. It is to be expected, therefore, that quartz crystals thus cooled will be irregularly and intricately twinned after (1010.), while low temperature quartzes are simple or regularly twinned. It is furthermore evident, on considering the genesis of quartz at different temperatures, that intergrowths of right and left handed quartz are limited chiefly to quartz crystals formed below 570 degrees. These two criteria can be used to distinguish quartz which has been formed or heated above 570 degrees from quartz which has never reached that temperature. The object of the present investigation has been to test the general validity of the theoretical conclusions on a number of quartzes from different kinds of rocks and veins, as well as to determine more accurately the inversion temperature.

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[1] Introduced by Wm. Bullock Clark.

[2] Introduced by F. P. Gulliver.

SESSION OF THURSDAY, DECEMBER 31

The sectional meetings for papers on stratigraphic, areal, and paleontologic geology was called to order at 10 o'clock Thursday morning by W. B. Clark, who was then elected presiding officer. E. R. Cumings acted throughout as secretary by request of the Secretary of the Society.

The first paper read was

OCCURRENCE OF THE MAGOTHY FORMATION ON THE ATLANTIC ISLANDS

BY ARTHUR BARNEVELD BIBBINS

[*Abstract*]

The Magothy formation (of mid-Cretaceous age), as originally defined by Darton, was supposed by that author to be limited to the state of Maryland, although its partial equivalent, the "alternate clay-sands," was earlier mentioned by Uhler as occurring much farther northward. Recent investigations, paleobotanical and stratigraphic, by Hollick, Berry, and the writer, have extended the lines of the formation far southward, and northward across New Jersey and along the Atlantic islands as far as Marthas Vineyard. The occurrence on these islands was shown by local sections and photographs. The deposits are richly plant bearing, with grains of amber associated, as on the Magothy river. The formation suffered considerable corrugation by the great ice-sheet.

The paper was discussed by David White and A. B. Bibbins.

The next paper read was

EROSION INTERVALS IN THE TERTIARY OF NORTH CAROLINA AND VIRGINIA[1]

BY BENJAMIN L. MILLER

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INTRODUCTION

In the Atlantic Coastal plain the recognition of unconformities is not an easy matter. This is due to several causes. In the first place, the formations in general represent littoral deposition, and the character of the materials changes very rapidly, both horizontally and vertically. For this reason it is difficult to definitely recognize the same formation by its lithologic characteristics over wide areas except where we have continuous exposures. Second, the covering of Pleistocene sands, gravels, and loams has concealed the underlying deposits over the stream divides to such an extent that outcrops can only be found at occasional intervals in the stream valleys. With practically all of the streams that are of sufficient size to have cut through this surface covering, flowing in the same general direction—to the southeast—there are few continuous exposures from one major drainage basin to the other, and since the lithologic characteristics may be dissimilar in two adjacent valleys, it becomes impossible to determine definitely whether the strata in the two places represent the same beds or not. Further, the fossiliferous strata occur in the form of lenses of variable extent separated by non-fossiliferous strata. Thus the absence of a fossil layer in one valley and its presence in an adjacent one does not necessarily mean that erosion has removed it from the former place. Again, the dip of the strata composing the Coastal plain is slight, especially in the case of the Tertiary strata, seldom exceeding 15 to 20 feet per mile. This varies somewhat in the different formations, though it is very unusual to have two formations in contact that exhibit different inclinations of sufficient magnitude to prove the presence of an erosional unconformity between them.

During the Tertiary period there is evidence to prove the submergence and elevation of the Coastal plain as a whole a number of different times, although seldom was the region elevated sufficiently to permit streams to carve valleys of any considerable depth before a succeeding depression took place. For the reasons given above, throughout the Coastal plain generally the various formations recognized are apparently conformable in that few irregular lines of contact can be discovered between them. The unconformities determined are mainly those of overlap. These overlap unconformities are exhibited in the northern part of the Atlantic Coastal plain in New Jersey, Delaware, and Maryland particularly, and have been described in the published literature. Similar unconformities are recognized in Virginia, and no doubt they have

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[1] Manuscript received by the Secretary October 15, 1909.

been equally prominent in North Carolina, though there we have less evidence for determining their presence, while there is much more evidence of the deposition of each formation upon an irregular erosion surface of earlier formations.

In the Coastal plain of Virginia and North Carolina the Tertiary strata have been studied in detail only within the last few years, and as yet the divisions recognized have not appeared in print. For this reason it is well to speak briefly of the formations.

EOCENE FORMATION

In Maryland the Eocene consists of two formations, the Aquia and the Nanjemoy, which are, so far as determinations can be made, perfectly conformable, though resting upon the underlying marine Cretaceous which they gradually overlap, and in southern Maryland and Virginia they extend over the edges of the marine Cretaceous and come to rest upon the underlying deposits of the Potomac group. The marine Cretaceous does not appear in Virginia because of this overlapping cover of Eocene strata, though it makes its reappearance in North Carolina, where the Eocene deposits have suffered much erosion. The Eocene formations of Maryland extend across the Potomac river, and reappear with the same lithologic and paleontologic characteristics in Virginia, extending a number of miles to the eastward of the "fall line," and extending southward as far as the James River drainage basin. From that point southward the Eocene is covered up by later deposits of Miocene and Pleistocene materials, and when the Roanoke and Tar River drainage basins in North Carolina are reached we find that the Eocene is entirely absent. In the valleys of those streams the Miocene is found everywhere resting directly on the underlying Cretaceous. In the southern part of North Carolina the Eocene reappears, and there we find it again represented by two formations, though these are distinctly different from the Eocene strata of Virginia and Maryland. Lithologically the difference is very striking, in that the glauconitic phase of the northern Coastal Plain Eocene is lacking, and in its stead we have deposits of fine-grained calcareous marls or limestones. Lithologically the North Carolina deposits belong to the Gulf phase rather than the North Atlantic Coastal Plain type. Also in the fossil content there is a marked difference between the North Carolina and the Virginia Eocene formations, though as yet the paleontologic work has not progressed far enough to definitely determine just how great a faunal gap exists between the two series. The more recent age of the North Carolina Eocene, however, is evident from the fossils. It seems probable that while deposition was going on in Virginia, Maryland, and New Jersey during the Eocene period, North Carolina remained above water because of the complete absence, so far as known, of the Pamunkey series. In North Carolina the two Eocene formations have received the names of Trent and Castle Hayne. The Trent formation is developed best along the Trent river, though it occurs in patches over a large part of the state. This formation contains fossils not recognized in any of the Eocene formations of Virginia and Maryland, the most noticeable form being the large species of *Ostrea georgiana.* This form is unknown north of North Carolina, though it occurs farther south, and is found in great abundance at the famous Eocene locality of Shell bluff, on Savannah river, a few miles below

Augusta, Georgia. The Trent formation rests on underlying strata of Cretaceous age along the Neuse and Trent rivers, and farther west is found in immediate contact with the underlying crystalline rocks of pre-Cambrian age. So far as known at present, the Trent formation has a wider inland distribution in North Carolina than any other Coastal Plain deposit. Isolated patches are known far to the west of the present "fall line," one of these occurring a few miles from Raleigh, and another one near Spout Springs, in Harnett county, while still other areas have been reported from Moore county, in all of which they overlie directly the crystalline rocks.

The second formation of the North Carolina Eocene has received the name of Castle Hayne because of its development in the vicinity of Castle Hayne on the northeast Cape Fear river. The lithologic characteristics of this formation are, as in the case of the Trent, distinctly calcareous, with little or no glauconite present, thus making it distinctly unlike the Eocene deposits of Virginia and Maryland. The fossils of this formation have not as yet received careful study, though Doctor Vaughan states that they form an entirely distinct fauna, unlike any known in South Carolina or in the Atlantic Coastal plain to the northward. The Castle Hayne formation outcrops in a very limited area in the southeastern part of the state, and wherever observed rests directly on Cretaceous strata belonging to the Peedee formation, and, further, it contains many Cretaceous shells that have been derived from these deposits. Several articles have already appeared in which the commingling of the Cretaceous and Eocene species in this formation at Castle Hayne and Wilmington have been described.

The distribution of the Trent formation in small isolated patches over such a wide area indicates extensive post-Trent erosion, and the fact that we find the Castle Hayne formation resting on Cretaceous strata proves that at least a part of the intervening Trent strata must have been removed before the deposition of the Castle Hayne formation.

Post-Eocene Interval

When we come to the Miocene we find that throughout the entire Coastal plain there is evidence of a considerable gap between the Eocene and the Miocene, though in Maryland it is scarcely possible to determine this unconformity except by overlap. In Virginia the same conditions exist, and there we find the Miocene gradually transgressing the Eocene to the westward until it comes to rest on the Piedmont crystalline rocks, entirely concealing the Eocene. In North Carolina the unconformity is much more pronounced, and there we find in many places Miocene beds resting on the Eocene deposits that occupy depressions in the irregular surface of the Cretaceous. Thus we find the Miocene resting on the Eocene in one locality, while a short distance away, at almost the same level, the Miocene is found in contact with the Cretaceous. The occurrence of Eocene deposits in pockets proves in a better way than in the case of the Maryland deposits an extensive erosion period separating the Eocene and Miocene. There is little doubt but that in the interstream areas of North Carolina beneath the covering of Pleistocene and Miocene strata there are many other patches of Eocene that have so far escaped observation.

MIOCENE FORMATIONS

In Maryland the divisions of the Miocene are three in number—Calvert, Choptank, and Saint Marys—and these with slight modifications extend across the Potomac river, and have been recognized in Virginia by their characteristic fossils and also similar lithologic materials. Besides, in Virginia a new formation makes its appearance that does not appear at the surface in Maryland, though it may be present in the eastern part of the state beneath the thick cover of Pleistocene materials. This is the Yorktown formation, so well exposed in the vicinity of Yorktown, on the York river. Of the three Miocene formations that extend across the Potomac river from Maryland, two of them—the Calvert and the Choptank—gradually disappear toward the southern part of the state, due to overlap or to non-deposition. The latter seems to be the case from what has been determined in North Carolina, where the Cretaceous is found immediately beneath the Saint Marys formation. In North Carolina we have three Miocene formations—the Saint Marys, which extends in an unbroken band from Maryland entirely across the state of Virginia; the Yorktown, which first appears as a surface formation in the vicinity of the York river, in Virginia, and which is continuous to the vicinity of the Neuse river, in North Carolina, though concealed in greater part in the interstream areas, and the Duplin, which occurs in isolated areas in the southern portion of the state and under similar conditions in the northern part of South Carolina. The Saint Marys formation, in the northern part of the state, rests on the Cretaceous or the crystalline rocks. Near Halifax a stratum containing well preserved molluscan shells is found in immediate contact with the decayed crystallines of the Piedmont plateau. Along the Tar river many exposures show the Saint Marys formation in contact with the lowest member of the Cretaceous. North of the Neuse river, in North Carolina and all through Virginia, the Saint Marys formation seems to be continuous and is exposed in the valley of each of the major streams. South of the Neuse river it is doubtfully represented in only a few localities, and there occurs as isolated patches of small extent.

The Yorktown formation makes its appearance in the vicinity of the York river in Virginia, and from there extends southward as a continuous band to the Neuse river, and throughout this belt rests on the Saint Marys formation with no marked unconformity. Tracing the deposit over a considerable area, however, it is found to be unconformable, and the basal stratum, consisting of fragmental shells of beach origin, indicates an uplift of the region before the deposition of the Yorktown. The fact that we find the Saint Marys present so extensively to the north of the Neuse river and find only patches of it southward would seem to indicate its original distribution as a continuous formation over a large part of the Coastal plain. Further, the fact that we now find the Yorktown resting directly on strata of Eocene age in the vicinity of Newbern, between the Trent and Neuse rivers, implies an erosion interval of considerable duration after the deposition of the Saint Marys and before the laying down of the Yorktown strata.

The Yorktown, in its turn, south of the Neuse river, suffered much erosion prior to the opening of the Pliocene period, and perhaps since the Pliocene as well. The Duplin formation is found in isolated areas along the Cape Fear river, in Duplin county, and southward. It is best known in Duplin county, North Carolina, where it is so well developed in the natural well near Magnolia. It is unknown in Virginia or in northern North Carolina, but has been recognized in several places in South Carolina. No doubt it is of the same age as some of the beds in the vicinity of Darlington and on the Peedee river in South Carolina. The Duplin formation, disappearing northward near the line where the Yorktown appears, might suggest their equivalency were it not for the fact that the Duplin strata contains a much more recent fauna.

Pliocene Formation.

Marine Pliocene deposits are unknown in Maryland and Virginia, though certain beds in the vicinity of the Dismal swamp in Virginia have been referred to this period. The evidence gained during the last year, however, seems to prove conclusively that the beds referred to the Pliocene in that section are in reality Pleistocene. Marine Pliocene beds, however, do appear in the southern portion of North Carolina. They are well developed along the Cape Fear river at Neills Eddy landing and Walkers bluff and in the vicinity of Croatan, south of the Neuse river. Also along the Waccamaw river, in South Carolina, the Pliocene is well developed, overlying the Peedee formation of the Cretaceous. The Cape Fear River deposits have been referred to the Waccamaw formation, and the fossiliferous strata near Croatan to the Croatan formation. It is not improbable that the latter deposits may eventually be referred to the Pleistocene, though they contain certain fossils that have usually been regarded as distinctly Pliocene types. At Neills Eddy landing and Walkers bluff the Pliocene is found in contact with the Cretaceous. Fossils of Peedee age are contained in the strata immediately underlying the Pliocene beds at the latter place.

Summing up the evidence, we find that each one of the Tertiary formations in North Carolina is separated both from the underlying and the overlying formations by an erosional unconformity, and each formation is found in one place or another in immediate contact with the Cretaceous. In Virginia the unconformities are less noticeable.

Relations of the North Carolina Tertiary Formations

One of the most striking things brought out in the recent work is the presence of the sharp line of demarcation occurring in the vicinity of the Neuse river. We seem to have evidence in almost every period of uplift during the Tertiary of different conditions prevailing south of the Neuse river than to the northward. Each of the Tertiary formations is almost entirely confined to one side of the river. The evidence obtained in the recent investigations in North Carolina seems to indicate that in that state we have a sharp change both in the character of the fossils and in the lithology between the Coastal Plain region to the northward and that lying to the south. The northern part of North Carolina in almost every particular, so far as the Tertiary deposits are concerned, seems to properly belong to the region lying to the northward—Virginia and Maryland—while southern North Carolina, south of the Neuse river, forms an essential part of the southern Atlantic Coastal plain, extending southward to Florida and bordering the gulf of Mexico. Beside the evidence already given to support this view, we have also the increasing or decreasing prominence of the strata of different periods as we cross the Neuse River valley. North of the Neuse river the Eocene is wanting for a considerable distance, and when it appears in the northern part of Virginia presents a distinctive glauconitic character and extends northward through Maryland, but with a thickness scarcely exceeding 200 feet. South of the Neuse river the Eocene appears, presenting a calcareous phase, and gradually increases in importance until in the Gulf region, particularly in Alabama, it becomes of very great importance. The Miocene formations throughout Maryland, Virginia, and the northern part of North Carolina are especially well developed and have received much attention. South of the Neuse river, in North Carolina, they are still represented, but with greatly decreased importance, and throughout the Gulf region the Miocene is distinctly subordinate in thickness and areal extent to the Eocene. The Pliocene period also shows similar characteristics. As already stated, the marine Pliocene, so far as we know, is entirely absent north of the Neuse river, but southward it appears in isolated patches in North Carolina, and also is represented southward to the gulf and becomes increasingly more important.

"HATTERAS AXIS"

Earlier workers have discussed the so-called "Hatteras axis" separating the Coastal plain in two portions, though the evidence was somewhat meager. The study of the Tertiary strata of North Carolina furnishes data for drawing this line of separation between the North and South Atlantic Coastal plains much more definitely. In general this line is followed by the Neuse river, as stated on a previous page. This line may be considered as an axis, in that denudation and sedimentation during each of the Tertiary periods were unlike on the two sides, and in most instances denudation south of the axis seems to have occurred at approximately the same time that deposition was taking place to the northward, and *vice versa.* The faunal studies which are now being carried on are expected to throw additional light on this problem.

Then was presented orally by the senior author

CHARACTER AND STRUCTURAL RELATIONS OF THE LIMESTONES OF THE PIEDMONT IN MARYLAND AND VIRGINIA

BY EDWARD B. MATHEWS AND J. S. GRASTY

[*Abstract*]

A study of the small bodies of crystalline limestones and marbles found along the western edge of the Piedmont from Pennsylvania to North Carolina shows that their occurrences mark the tops of tightly compressed anticlines. The deposits on either side are usually metamorphosed volcanics—flows and tuffs—which in the normal section lie far beneath the limestones. The areal distribution, contacts, and structural lines point to a strong overthrust fault of wide extent.

This paper was discussed by J. Barrell.

RECURRENCE OF THE TROPIDOLEPTUS FAUNA IN THE CHEMUNG OF MARYLAND[1]

BY CHARLES K. SWARTZ

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RECURRENCE OF FAUNAS

The occurrence of a fauna characteristic of one geological formation within the limits of another formation is a phenomenon of much interest, since it affects the problem of the correlation of geological horizons.

Barrande first clearly pointed out the possibly of the occurrence of one fauna in the midst of another in his now famous doctrine of colonies. While his interpretation of the sections studied by him has proved erroneous, the principle enunciated has been of great importance, especially in suggesting the conception of the simultaneous existence of independent faunas in different areas. Williams[2] subsequently applied the same principle to the Upper Devonian strata of New York, and his work has been extended by many other students of the problem.

Four recurrences of the Hamilton fauna, termed by Williams the *Tropidoleptus carinatus* fauna, are recorded by him in the Upper Devonian strata of New York above the summit of the Hamilton formation.[3] The uppermost of these horizons lies within the Chemung of that state.

The existence of similar recurrent faunas in the Chemung of Maryland has recently been observed by the author, and he believes that the facts observed and certain conclusions based upon them, may be worthy of communication. A brief historical statement will be helpful in understanding the discussion.

HISTORICAL REVIEW

The Upper Devonian of Maryland presents two well defined facies, a lower marine division and an upper division having the characteristics of the Catskill of New York.

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[1] Published by permission of the Director of the Maryland Geological Survey. Manuscript received by the Secretary of the Society June 5, 1909.

[2] Proceedings of the American Association for the Advancement of Science, vol. xxx, 1881, p. 186. U. S. Geological Survey, Bull. no. 3, 1884.

[3] Journal of Geology, vol. xv, 1907, pp. 108-110.

The lower marine strata are known as the Jennings formation. This formation has long been recognized as equivalent, in a general way, to the Genesee, Portage, and Chemung of New York. The Jennings of Maryland has been studied by Professor C. S. Prosser, who has prepared a monographic treatment of the subject to be issued in the forthcoming volume of the Maryland Geological Survey, upon the Devonian of Maryland. An extended and admirable study of the fauna was made by Dr J. M. Clarke, of Albany, New York, whose work will appear in the same volume. A brief summary of the results obtained by these workers was published by Professor Prosser in the Journal of Geology in 1901.[4]

The author wishes to acknowledge his indebtedness to these two gentlemen, with whose work he has been acquainted, in advance of its full publication, in the prosecution of his own studies. A full statement of their results will appear in the volume mentioned.

The author subsequently showed that a fauna similar to the Ithaca fauna of New York occurs in the Portage of Maryland, and that this is succeeded by a fauna of marked Hamilton type, frequently abounding in *Tropidoleptus carinatus*, which occurs in the Portage below the strata containing the typical Chemung species.[5]

At the time of the publication of the paper referred to, the occurrence of the *Tropidoleptus carinatus* fauna above the base of the Chemung fauna had not been observed by the writer and his associates.[6]

During the past summer *Tropidoleptus carinatus* and associated Hamilton species have been observed about 600 feet above the base of the Chemung fauna. It is to record this occurrence that the present communication is made. The author wishes to acknowledge his great indebtedness to Professor D. W. Ohern, to whom he is under obligations for constant and most intelligent cooperation in the prosecution of this entire investigation, and to Dr T. P. Maynard, who has assisted in measuring certain of the sections described.

Before considering the fauna it will be helpful to discuss the lithological sequence in the Upper Devonian of Maryland.

Lithological Sequence

The Jennings of Maryland embraces nearly 5,000 feet of strata. At the base, in the west, are the black shales of the Genesee member. Above this succeed argillaceous shales alternating with thin sandstones, the percentage of sandstone increasing in the upper part of this zone. These shales and interbedded flaggy sandstones bear the Naples fauna as in New York. They are succeeded by slightly more arenaceous sediments bearing a profuse development of the Ithaca fauna characterized by the dominance of *Spirifer penatus* var. *posterus* Hall and Clarke. Overlying the latter appear more arenaceous sediments containing prominent conglomerates in the east and bearing a profuse fauna of distinctly Hamilton type, dominated by the presence of *Tropidoleptus carinatus*

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[4] Journal of Geology, vol. ix, 1901, pp. 419-420.

[5] Journal of Geology, vol. xvi, 1908, p. 328.

[6] Professor Prosser had observed the occurrence of *Tropidoleptus carinatus* in his study of the Jennings, but had not determined its horizon with respect to the succession of faunas here discussed.

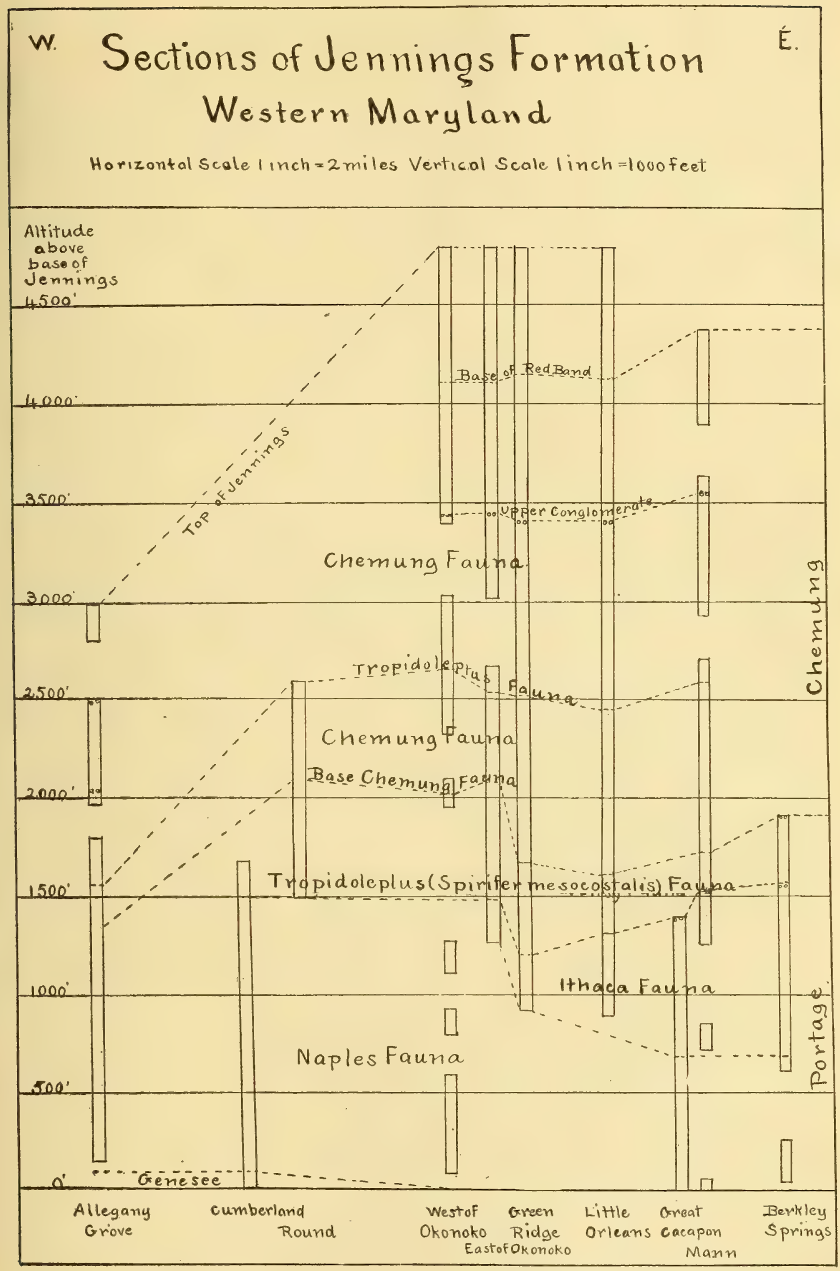
W.
E.
Sections of Jennings Formation
Western Maryland
Horizontal Scale 1 inch = 2 miles Vertical Scale 1 inch = 1000 feet
Altitude above base of Jennings
4500'
4000'
3500'
3000'
2500'
2000'
1500'
1000'
500'
0'
Top of Jennings
Base of Red Band
Upper Conglomerate
Chemung Fauna
Tropidoleptus Fauna
Chemung Fauna
Base Chemung Fauna
Tropidoleplus (Spirifer mesocostalis) Fauna
Ithaca Fauna
Naples Fauna
Genesee
Chemung
Portage
Allegany Grove
Cumberland
Round
West of Okonoko
East of Okonoko
Green Ridge
Little Orleans
Great Cacapon
Mann
Berkley Springs

FIGURE 1.—*Sections of Jennings Formation, Western Maryland*

Conrad and *Spirifer mesacostalis* Hall. Above these succeed typical Chemung sediments containing a Chemung fauna. The percentage of sandstone increases in general in ascending in the section.

In the central part of the area, at an altitude of about 600 feet above the base of the *Spirifer disjunctus* fauna, appears a zone usually conglomeratic and containing massive sandstones eastward, which bears at places a profuse development of *Tropidoleptus carinatus* and associated species of Hamilton type. This is in turn succeeded by the *Spirifer disjunctus* fauna. The *Tropidoleptus carinatus* fauna is thus a recurrent fauna of Hamilton type lying within the Chemung fauna of Maryland. The occurrence of this recurrent fauna in the various sections will now be discussed.

SECTIONS EAST OF WILLS MOUNTAIN

SECTION 1¾ MILES SOUTH OF ROUND, WEST VIRGINIA

This fauna was first observed on the farm of John Will Smith, about 1¾ miles south of Round, West Virginia. At this point the strata occupy the axis of a syncline and are nearly horizontal. A massive sandstone bearing *Camarotœchia congregata* (Conrad), *Spirifer mesacostalis* Hall, etcetera, occurs about 1,100 feet below the top of the section. Six hundred feet above the latter *Spirifer disjunctus* was found. This horizon is overlaid by heavy red sandstone cropping out on the hillsides. The summit of the hill is formed by massive gray sandstones and conglomerate, which bear a profusion of *Tropidoleptus carinatus*. The following species were collected at this horizon:

Tropidoleptus carinatus (Conrad) *ab.*
Spirifer marcyi Hall var. *c.*
Ambocœlia umbonata (Conrad).
Rhipidomella vanuxemi Hall.
Camarotœchia sappho Hall.

Tropidoleptus carinatus is profuse and typical. *Spirifer marcyi* is a variety with an unusually high area and massive appearance, but admits of no doubt of the identification. All of the species are characteristic of the Hamilton.

SECTION WEST OF OKONOKO

A similar conglomerate appears at an altitude of 2,650 feet above the base of the Jennings in the section on the Western Maryland railroad west of Okonoko, north of the Potomac river, on the west side of Green ridge. *Spirifer disjunctus* appears in the section at 2,000 feet above the base of the Jennings. The following faunule was secured at about 2,670 feet:

Tropidoleptus carinatus (Conrad)
Spirifer marcyi Hall
Ambocœlia umbonata (Conrad)

SECTION WEST OF PAWPAW

Numerous excellent exposures occur in the vicinity of Pawpaw. A very massive sandstone, slightly conglomeratic, forms the summit of the Devils Nose. On the west slope of the mountain, along the Baltimore and Ohio railroad, a lower massive conglomerate is exposed, holding essentially the same position as the Tropidoleptus-bearing zone west of Okonoko. It bears *Tropidoleptus carinatus.* This species, and others found in the preceding sections, were observed at numerous points in the vicinity on the strike, lying about 500 to 700 feet above the base of the *Spirifer disjunctus* fauna. The latter is constantly underlain by the lower Tropidoleptus fauna, below which appears the Ithaca fauna. It is thus possible to trace a continuous horizon, which is very conglomeratic in the east, much less so in the west, and which bears *Tropidoleptus carinatus* lying at an altitude of about 2,500 to 2,700 feet above the base of the Jennings.

MORE EASTERLY SECTIONS

A persistent and massive conglomerate appears at approximately the same altitude in the sections farther east. They have not yet been studied with respect to the occurrence of *Tropidoleptus carinatus*, but it is believed that they represent the same horizon.[7]

Sections West of Wills Mountain

SECTION NEAR ALLEGANY GROVE

When we pass west of Wills mountain the sections show marked faunal and lithological changes, though they are but a few miles distant from the most westerly sections previously described.

The best section of the region is near Allegany Grove, about four miles southwest of Cumberland, along the Cumberland and Potomac, and the Georges Creek and Pennsylvania railroads. The lower part of the section consists largely of argillaceous shales. At an altitude of about 800 feet above the base of the Jennings, *Camarotœchia* sp. was found in somewhat more arenaceous sediments. At an altitude of 1,360 feet *Spirifer disjunctus* occurs. At 1,560 feet massive sandstones develop. The *Tropidoleptus carinatus* fauna is found in these strata a short distance south of the railroad. At 1,900 feet a heavy conglomerate appears associated with gray and brown sandstones. At 2,600 feet is a second massive conglomerate, which is revealed only by fragments in the section on the railroad. Several other less prominent conglomerates are seen above this. The Catskill appears at the east end of the tunnel at an altitude of 3,000 feet above the base of the section.

SECTION NEAR ELLERSLY

At Ellersly, 6½ miles northeast of the preceding section on the strike, a profuse development of *Dalmanella tioga* (Hall), *Spirifer disjunctus*, and other characteristic Chemung forms appears at an elevation of about 1,300 feet. The same zone may be traced southwestward nearly to the Potomac river, showing that the *Spirifer disjunctus* fauna appears at about 1,300 or 1,400 feet above the base of the section. *Tropidoleptus carinatus* was observed abundantly at a number of points southwestward on the strike in what appears to be the massive sandstone occurring at 1,560 feet altitude in the Allegany

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[7] Since the above was written the *Tropidoleptus carinatus* fauna has been found at the appropriate horizon in the section near Mann, east of Sideling Hill.

Grove section. This fauna therefore lies above a strongly developed Chemung fauna containing numerous *Spirifer disjunctus* Sowerby, *Dalmanella tioga* (Hall), *Pterinea chemungensis* Conrad, etcetera.

Correlation of the various Sections

An examination of the various sections (see accompanying chart) shows that there are certain persistent horizons which may be traced throughout the region. The black shales of the Genesee form the base of the Jennings in the western sections, thinning out and disappearing eastward. Above the latter, or at the base of the Jennings in their absence, occur shales and interbedded flaggy sandstones resembling the Sherburne of New York and carrying the Naples fauna, as in that state.

These are overlain by shales containing the Ithaca fauna in the eastern sections. This fauna disappears west of Green ridge.

These strata are succeeded by the lower *Tropidoleptus carinatus* (*Spirifer mesacostalis*) zone,[8] characterized by a profusion of *Tropidoleptus carinatus* (Conrad), *Spirifer mesacostalis* Hall, and associated species of Hamilton type. This zone is conglomeratic in the east, but is represented by sandstones westward, where the conglomerates disappear.

The *Spirifer disjunctus* fauna overlies the preceding, being found about 1,800 to 2,000 feet above the base of the Jennings in the eastern sections and at about 1,300 feet above the base of the formation west of Wills mountain. The Tropidoleptus fauna recurs at an altitude of about 2,600 to 2,700 feet above the base of the Jennings in the middle part of the area, associated with conglomerates and sandstones which become less massive westward. This fauna can be traced at about the same altitude from the sections east of Pawpaw, West Virginia, to the vicinity of Round, West Virginia. A similar fauna occurs about 200 feet above the base of the *Spirifer disjunctus* fauna and about 1,500 feet above the base of the Jennings, west of Wills mountain. It is, however, not possible at present to correlate the latter confidently with the upper Tropidoleptus zone of the earlier sections.

The upper part of the section contains massive conglomeratic sandstones. The Jennings is overlain by red strata of Catskill type.

J. J. Stevenson, in his vice-presidential address before the American Association for the Advancement of Science,[9] calls attention to the existence of two well defined conglomerate horizons in the Upper Devonian of Pennsylvania and adjoining states which he correlates over wide areas. He terms the lower of these the Allegrippus and the upper the Lackawaxen conglomerate, names introduced by I. C. White. He believes that they are persistent over large areas and that they can be recognized in regions immediately adjoining Maryland.

A careful examination of the section shows that in Maryland the problem is much more complex. There are not two, but many conglomerates in the section. These conglomerates are very variable in their local development. The conglomerates of the east may be replaced by sandstones in the west, while other conglomerates develop at higher horizons. It thus seems to the author to be very hazardous to attempt a correlation of the conglomerates over a large area by their position in the section without faunal evidence, which has not yet been secured.

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[8] See discussion of this fauna, Journal of Geology, vol. xvi, 1908, p. 308.

[9] Proceedings of the American Association for the Advancement of Science, vol. xl, 1891 (1892), p. 219.

Correlation with the Upper Devonian of New York

The comparison of the sequence of the Upper Devonian strata in Maryland, as shown by the above sections, and that in New York, recorded by Williams,[10] shows a striking similarity.

Section in Maryland	Section at Ithaca, New York
Sandstones and shales	
Upper conglomerate, 25–50	Fall Creek conglomerate, 0–10
Sandstone and shales, 700–800	Wellsburg sandstone, 600–650
Upper Tropidoleptus carinatus Zone	*Tropidoleptus carinatus Zone*
Shales and sandstone, 500–700	Cayuga shale, 600
Lower Tropidoleptus carinatus Zone (*Spirifer mesacostalis Zone*), 300-600	Enfield shale (with recurrent Tropidoleptus fauna), 550–800
Shales and sandstone, Ithaca fauna	Ithaca shale
Shales and sandstone with Naples fauna	Sherburne flagstone with Naples fauna
Genesee, absent in east	Genesee

The sequence of the faunas is the same, both in New York and in Maryland, while there is a marked similarity in the lithological features. The close similarity of the sections, both lithologically and faunally, is striking and indicates that the Upper Devonian of Maryland and New York were laid down in a common basin and under similar conditions.

Geographical Range of the Genera Dalmanella and Douvillina in Maryland

In examining the distribution of the species of the Chemung fauna certain features are to be noted. Species of the genus Dalmanella are very rare east of the Wills Mountain anticline. Up to this time the author and his associates have not observed a single specimen of Dalmanella east of Wills mountain, and but a single valve has been reported from that region by others. West of Wills mountain, on the contrary, they are abundant. Again, species of Douvillina are not common east of the same locality, while they are very abundant west of it. *Spirifer disjunctus*, however, is abundant throughout the area.

A somewhat comparable condition seems to exist in New York, where Williams[11] does not cite any species of Dalmanella from the eastern part of the state in his recent paper on the genus Dalmanella. The reason for these facts is not clear. Wills mountain is the high western arch of the Alleghany mountains. The marked difference in the fauna east and west of it suggests the possibility that the arch may have begun to rise early in Upper Devonian time, forming a submerged barrier at that time. This is a mere suggestion, however, and needs further confirmation before being worthy of acceptance.

The facts given may be summarized in the following conclusions:

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[10] Williams: Devonian section of Ithaca, N. Y. Journal of Geology, vil. xiv, p. 579.

[11] Proceedings of the U. S. National Museum, vol. xxxiv, 1908.

CONCLUSIONS

Two recurrences of the *Tropidoleptus carinatus* fauna are recorded in the Upper Devonian of Maryland, one in the upper part of the Portage and one about 600 feet above the base of the Chemung, in the central part of the Upper Devonian area.

A marked similarity exists in the succession of faunas as well as in the lithological features of the Upper Devonian strata of Maryland and New York, suggesting that these strata were laid down in one basin of deposition under similar conditions.

Certain differences in the faunas east and west of Wills mountain suggest the possibility of the existence of some form of a low barrier in this locality in Chemung time.

GEOLOGICAL DISTRIBUTION OF THE MESOZOIC AND CENOZOIC ECHINODERMATA OF THE UNITED STATES[1]

BY W. B. CLARK AND M. W. TWITCHELL

[*Abstract*]

Echinoderm remains are found in America in the deposits of every period from the Triassic to the Recent, but are by far the most significant in those of Cretaceous and Eocene age. In several formations they are among the most valuable of diagnostic fossils, while at a few localities they occur in vast numbers.

Comparatively few *Triassic* forms have been found. The most common are crinoid stems, representing the genera *Pentacrinus* and *Encrinus*, the former found in both the Lower Triassic of Idaho and the Upper Triassic of California, and the latter confined to the Upper Triassic of California. The echinoids are represented by two species of *Cidaris*, which are confined to the Upper Triassic of California. In addition to these a few indistinct casts, among them a small, poorly preserved starfish, which has been questionably assigned to the genus *Aspidura*, have been found in the Lower Triassic of Idaho.

The *Jurassic* echinoderms are somewhat more numerous and varied, although they do not constitute an important element in the fauna. As in the Triassic, the most common forms belong to the genus *Pentacrinus*, column joints having been found in Nebraska, South Dakota, Wyoming, Colorado, Idaho, Utah, and California. The asteroids are represented by both the Ophiuridæ and Stelleridæ, specimens having been found in Wyoming, South Dakota, and Utah. The echinoids are much more fully represented than in the Triassic. Several genera have been recognized, among them *Cidaris*, *Hemicidaris*, *Pseudodiadema*, *Stromechinus*, *Holectypus*, and *Pygurus*. The specimens are in the main poorly preserved and are rarely numerous. The first four genera occur only in California, being found in both the Lower and Middle Jurassic. One species of *Holectypus* occurs in Texas and another in Montana, while *Pygurus* has only been found in Texas.

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[1] Published by permission of the Director of the U. S. Geological Survey. A monographic study of the Mesozoic and Cenozoic Echinodermata of the United States has been made by the authors. Manuscript received by the Secretary of the Society May 27, 1909.

The *Cretaceous* echinoderms are very numerous in certain areas. A great variety of types is represented and the material is oftentimes splendidly preserved. Many of the species are narrowly limited in geological range and therefore are important as type fossils.

The crinoids are represented by *Uintacrinus*, *Pentacrinus*, and *Rhizocrinus*, this first genus having afforded a great number of remarkable specimens in the Niobrara chalk of Kansas. Springer has made this material the subject of an elaborate monograph, and most of the great museums of the world contain beautiful specimens from the now famous locality in Kansas.

The asteroids contain representatives of both the Ophiuridæ and the Stelleridæ, the genera *Ophioglypha*, *Astropecten*, *Goniaster*, *Pentagonaster*, and *Pentaceros* being found. The material comes from widely separated areas in New Jersey, Texas, and Wyoming.

The echinoids are very numerous, both the regular and irregular types being well represented. The Lower Cretaceous deposits of Texas contain vast numbers of individuals at several horizons and in certain areas, while the Upper Cretaceous of the Atlantic and eastern Gulf coasts, particularly in New Jersey, North Carolina, Alabama, and Mississippi, although less fully characterized by its echinoid fauna, affords many forms. The western Interior and Pacific Coast Cretaceous contains a much smaller representation of echinoid types.

Among the Lower Cretaceous genera found represented more particularly in Texas are: *Cidaris*, *Leiocidaris*, *Salenia*, *Hypodiadema*, *Goniopygus*, *Pseudodiadema*, *Diplopodia*, *Heterodiadema*, *Cottaldia*, *Pedinopsis*, *Orthopsis*, *Cyphosoma*, *Micropsis*, *Holectypus*, *Pyrina*, *Ananchytes*, *Holaster*, *Enallaster*, and *Hemiaster*, the last furnishing many species. Outside of Texas very few Lower Cretaceous echinoids have been recognized, the Horsetown beds of California containing a few forms.

The Upper Cretaceous of the Atlantic and Gulf coasts has afforded representatives of the following genera: *Cidaris*, *Salenia*, *Pseudodiadema*, *Coptosoma*, *Psammechinus*, *Echinobrissus*, *Trematopygus*, *Botriopygus*, *Cassidulus* (many species of which have been recognized), *Catopygus*, *Echinanthus*, *Ananchytes*, *Cardiaster*, *Hemiaster*, and *Linthia*. Much the larger number of forms have been found in the New Jersey Cretaceous, especially the Vincentown limesand bed of the Rancocas formation, which is regarded as probably of Danian age. The western Interior and Pacific Coast areas contain few representatives of the echinoids, most of the species belonging to the genus *Hemiaster*.

The *Eocene* deposits have afforded a considerable number of echinoderms, but they are less numerous than in the Cretaceous. They are found at various Eocene horizons on the Atlantic and Pacific coasts, but are most numerous and characteristic in the South Atlantic and Gulf Eocene, where they occur in large numbers. Nearly all of the echinoderm materials belong to the group of the echinoids, although representatives of the Crinoidea, Asteroidea, and Holothuroidea have been found. Among the echinoid genera recognized are *Cidaris*, *Cœlopleurus*, *Echinocyamus*, *Sismondia*, *Scutella*, *Mortonia*, *Breynella*, *Echinolampas*, *Clypeaster*, *Cassidulus*, *Hemipatagus*, *Brissopsis*, *Ditremaster*, *Linthia*, *Schizaster*, *Eupatagus*, *Macropneustes*, *Sarsella*.

The *Oligocene* strata of the South Atlantic and Gulf areas have not been in many instances satisfactorily delimited from the Eocene, so that the age of some of the echinoid material can not be with certainty determined. Among the known Oligocene genera of the South Atlantic and Gulf areas are *Cidaris*, *Sismondia*, *Laganum*, *Amblypygus*, *Oligopygus*, *Cassidulus*, and *Eupatagus*. The great majority of the forms come from Florida. The Oligocene deposits of California have also furnished specimens of *Cidaris*.

The *Miocene* deposits of both the Atlantic and Pacific coasts have afforded a considerable number of echinoderms, chiefly echinoids. The Atlantic Coast Miocene contains *Ophioderma* (?), *Cidaris*, *Cœlopleurus*, *Psammechinus*, *Scutella*, *Encope*, *Mellita*, *Agassizia*, *Brissus*, *Plagionatus*, and *Echinocardium*. The Pacific Coast Miocene, on the other hand, has furnished *Asterias*, *Amphiura*, *Cidaris*, *Scutella*, *Clypeaster* (?), *Astrodapsis*, and *Linthia*.

The *Pliocene* deposits contain very few echinoderms. On the South Atlantic coast from the Carolinas southward a few forms have been recognized, among them *Strongylocentrotus*, *Encope*, and *Clypeaster*. On the Pacific coast *Astrodapsis*, *Scutella*, and *Schizaster* (?) are found. The Miocene and Pliocene echinoids of the Pacific coast have been found to be of more than ordinary value in the determination of geologic horizons. This is due to their limited geologic range and to the fact that, where present at all, they are usually abundant and well preserved.

The *Pleistocene* deposits likewise have furnished very few echinoderms, and those for the most part of species living in the adjacent seas. Among those recognized from the Atlantic border have been *Asterias*, *Asteracanthion*, *Strongylocentrotus*, *Mellita*, *Moira*, and *Taxopneustes*. On the Pacific coast, on the other hand, several species of *Strongylocentrotus* and *Scutella* are found.

The paper was discussed by John M. Clarke and W. B. Clark.

The next paper read was

AGE OF THE GASPÉ SANDSTONE[*]

BY HENRY SHALER WILLIAMS

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Former Explanation of Mixture of Hamiltonian and Oriskanian Species in fauna of Gaspé Sandstone (York River Beds)

In a recent report by the State Geologist of New York[1] the invertebrate fauna from the lower part of the Gaspé sandstone is described as having a remarkable combination of two faunas, the species of which are generally regarded as characteristic of the Oriskany and Hamilton formations respectively.

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[*] Manuscript received by the Secretary of the Society January 8, 1909.

[1] J. M. Clarke: Early Devonic history of New York and eastern America, 1908.

In speaking of the age of these deposits Doctor Clarke says:

> "The Hamilton species indicate the introduction and the prevalence of a fauna and a geologic stage much later than the Oriskany" . . . and "the prevalence of the Hamilton fauna" . . . "indicates a northeast passage at this date from the Appalachian gulf through which the fauna departed eastward along the continental border."

Paleontologists were already familiar with a similar association of Hamiltonian types with Oriskany or Helderbergian types in the Saint Helens Island breccias, regarding which Dr H. M. Ami,[2] Mr Charles Schuchert,[3] and Dr J. F. Whiteaves[4] have each expressed similar views as to age.

In reporting to Dr F. D. Adams on the age of certain fossils from Saint Helens island and Coté Saint Paul, I also called the Upper Saint Helens fauna Oriskany[5] and the Coté Saint Paul fauna Hamilton,[6] though the Coté Saint Paul fauna contains species also found in the Upper Saint Helens beds.

Reasons for Reviewing former Interpretations

In the light of recent investigations regarding the geographic conditions of the areas concerned, made by Messrs Ulrich, Schuchert, Willis, Grabau, J. M. Clarke, Weller, and others, as well as my own, I have reviewed the whole body of evidence bearing on the age of the formations containing the mixed faunas, reaching the conclusion that all of us may have given too much weight to the Hamiltonian aspect of the fossils.

As a correct interpretation of the facts involves the right use of fundamental principles of correlation and has an important bearing on the origin of the faunas concerned, I will state briefly the reasons for the conclusions I have reached.

The Gaspé sandstones are a series of sandstones and conglomerates of about 7,000 feet thickness, overlying the 2,000 feet of limestones called the Saint Albans, Cape Bon Ami, and Grande Grève limestones cropping out on the Gaspé peninsula of New Brunswick.

In this Acadian province there is evidence of open marine seas at the close of the Silurian and early part of the Devonian periods, including the Niagaran and Helderbergian epochs. The outcrops lie northeast of Gaspé, extending at least to Anticosti island; extending south of Gaspé over Nova Scotia, as at Arisaig; to the southwest seen in the Cobscook and Ames Knob regions of Maine; west as seen in the Square Lake and Chapman formations of Aroostook county, and Temiscouata and other sections to the northwest along the south side of the Saint Lawrence in Quebec and at Littleton, Vermont.

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[2] Annual Report of the Geological Survey of Canada, n. s., vol. vii, 1896, pp. 155*j*-156*j*.

[3] American Geologist, vol. xxvii, April, 1901, p. 253.

[4] Vice-Presidential address, American Academy for the Advancement of Science, 1899, p. 16.

[5] Canadian Record of Science, vol. ix, 1903, pp. 56-57, based upon letter written by H. S. Williams to Dr F. D. Adams, dated May 16, 1902.

[6] Letter of H. S. Williams to Dr F. D. Adams, dated February 23, 1906, reporting on the fossils collected from Coté Saint Paul: the letter states that the fossils there found were "characteristic of the Hamilton formation as seen in Schoharie and Albany counties, New York state," adding that the fossils suggested "a sea opening for this region as late as the time of deposition of the Hamilton formation," and, further, "This discovery at Coté Saint Paul, if its origin upon the spot is certain, gives positive proof of the existence of marine conditions up to the time of living of the typical Hamilton fauna."

These faunas run up at least into early Oriskanian in the Chapman fauna of Aroostook county and the Moose River sandstones of Somerset county, Maine, and in Gaspé in the Grande Grève limestones, as shown by Doctor Clarke.

Near Montreal, on the north side of the Connecticut-Saint Lawrence trough, there is evidence of the Helderberg in the Lower Saint Helens fauna and, as I reported in 1902,[7] the Upper Saint Helens reaches the Oriskanian age.

Limestones at Owls head, lake Memphremagog, and farther east at river Chaudière contain fossils of Onondagaian age, thus bringing conclusive proof of marine waters in this eastern region to an epoch as late as Onondagaian.

The Upper Saint Helens Island fauna is also in evidence with its species of strongly Hamiltonian aspect and the block of limestone from the island of Coté Saint Paul, which I originally thought contained only Hamiltonian species.

Thus the evidence seems to be cumulative in favor of Doctor Clarke's hypothesis of Hamiltonian age for the Calcareous beds at the base of the Gaspé sandstones. The opinion has been growing with me, however, that this interpretation can not be correct, and recently I made a thorough review of the facts with the results which I am about to set forth. The reason for applying the test to the Gaspé series is because there the sequence is most complete, but the decision will apply to all the associated faunas in which the mingling of faunas appear.

Doctor Clarke has reported forty-nine species from the Gaspé sandstone; the marine invertebrates are almost all from the Calcareous beds at the base of the 7,000 feet Gaspé sandstones, which apparently follow conformably on the Grande Grève limestone.

In order to distinguish the beds and the fauna from the succeeding sandstones and conglomerates holding plants and brackish water types of fish, I have called these basal beds the York River beds, from the river emptying southeast of the small peninsula, where the main part of the fossils were obtained.

The number of species given names of Hamilton species and described as having Hamiltonian affinities exceeds the number of strictly Oriskanian species, which is the ground mentioned for calling the beds Hamiltonian in age. I have critically examined the list, and am inclined to think that Doctor Clarke has given undue weight to number of separate specific names, and has overlooked the intrinsic testimony of the larger number of individuals belonging to a few species of undoubted Oriskanian age.

There are forty-nine species in the list, but the four vertebrates and the Tropidocaris are not reported as associated with the marine fossils of the York River beds. There are seventeen names either new species or generic names without identification of species, thus leaving but twenty-seven species strictly identified with the species of known faunas.

Of the twenty-seven positively identified species, fourteen are listed in faunas of known Hamiltonian age, and thirteen have been listed in faunas of Oriskanian age. With this restriction the Hamiltonian species still have the advantage in number. But of the fourteen positively identified Hamilton species only three are indicated as common in the fauna; all the others, therefore, may be classed as not dominant in the York River fauna.

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[7] See Canadian Record of Science, vol. ix, 1903, pp. 56-57.

The three said to be at all common are *Cyrtina hamiltonensis, Nuculites triqueter,* and *Tropidodiscus rotalinea.*

The fact that *Cyrtina heteroclita,* certainly a very closely related species, ranges throughout the Lower and Middle Devonian of Europe diminishes the value of *Cyrtina hamiltonensis* as witness of the Hamiltonian age of the fauna. *Cyrtina dalmani,* which ranges lower than Oriskany, can not be regarded as far removed from the Hamilton species.

Nuculites triqueter can not be regarded as of much significance in making a close identification of the fauna because of its wide range as a genus, and also because of the exceedingly unsatisfactory characters it presents for specific identification, as shown by the fact that Professor Hall in the elaborate volume on the Lamellibranches of the Devonian of New York state in the preliminary publication placed four figures of the plate illustrating the genus in the newly described species *N. nyssa,* which in the final publication three years later he listed as *N. triqueter.* This leaves only one dominant species of the fauna positively correlating it with the Hamiltonian fauna.

On the other hand, the following species of Oriskanian age are in the list: *Rensselæria ovoides, Eatonia peculiaris, Leptocœlia flabellites, Orthothetes becraftensis, Chonetes hudsonicus, Chonostrophia dawsoni, Chonostrophia complanata,* and *Phacops correlator,* five of which are common or abundant species in the York River fauna, and all of them are dominant Oriskany species. Two other species, namely, *Spirifer gaspensis* and *Leptostrophia blainvillei.* are also dominant species in these York River beds at Gaspé, and though not reported outside of the eastern province are always found associated with well known Oriskany species. Thus ten of the thirteen positively identified species are dominant species in the particular fauna at Gaspé, and are also dominant species in Oriskanian faunas wherever they occur.

I can not escape the conviction that taking the list as given by Doctor Clarke the dominant species of Oriskanian affinities present a much stronger testimony as to the age of the fauna than do the Hamiltonian species, which although greater in number of species are poorly represented in the fauna.

But suppose we waive the differing values of the specific units in making up the average, granting for the argument that the evidence is as strong for the Hamiltonian as the Oriskanian elements of the fauna, is there any *a priori* reason why we must assume that the Oriskanian element lived on in this one locality until the Hamiltonian epoch? May not the same facts be interpreted as indicating the early appearance in the Oriskanian epoch of traces of the species which elsewhere did not appear till the Hamiltonian epoch? Not only the intrinsic evidence of the fauna bears out this conclusion, but the geographical evidence supports the same view.

The argument for Hamiltonian age is supported by the like association of species in the upper of the two Saint Helens Island faunas, where are found associated with species of Oriskany type other species of decided Hamiltonian type. This argument, however, is offset by the fact that the Coblenzian and other Lower Devonian faunas of Europe show a similar combination of species which in North America are either characteristic Lower Helderberg-Oriskany types or else are characteristic Middle Devonian types. If we suppose the Gaspé basin to have been in open communication with the sea eastward, is it not as easy to account for the forerunners of the Hamilton species in the Oriskanian of America as in the Lower Coblenzian of Europe?

There is, moreover, positive difficulty in accounting for the combination of species in the Hamiltonian epoch of North America. In order to account for the mixing of Hamilton species with Oriskanian it is necessary to imagine the Oriskanian species living through the Onondagaian epoch. Evidence of the Onondagaian fauna is known in the Chaudière River beds, but containing no trace of the dominant Oriskanian species supposed to have lived over except *Leptocœlia flabellites*, which is also known in the Onondaga formation of the interior, and no Hamiltonian fauna in the country has any mixture of Oriskanian species. The Chaudière beds are midway between the Gaspé and Saint Helens beds. How will we account for the continuance of the Oriskany species till Hamiltonian epoch without showing some trace of themselves in the interval or in the typical basin of Hamilton sediments, with which open connection with the Gaspé locality has been assumed?

Not only are the underlying Grande Grève limestones filled with a dominantly Oriskanian fauna, but the Nictaux beds, Nova Scotia, the Campbell River beds in New Brunswick, the Chapman sandstone in Aroostook county, the Moose River sandstone in Somerset county, Maine, and the Upper Saint Helens and Coté Saint Paul, near Montreal (thus quite surrounding the Gaspé peninsula), are all filled with a very closely allied fauna to that described from the York River beds at the base of the Gaspé sandstone. This gives strong ground for belief that there were open connected seas in which the fauna lived. But inside the Connecticut-Saint Lawrence trough not the least trace of the Onondagaian fauna is in evidence, and no hiatus or unconformity in the Gaspé section furnishes reason for supposing that the Gaspé series from the limestones upward through the sandstones was not a continuous deposition.

The combination of species in the York River beds at Gaspé, as well as in the Upper Saint Helens beds and at Coté Saint Paul, near Montreal, is remarkable in containing elements of two faunas mixed which we are accustomed to find dissociated. The dissociation of the separate faunas is, however, not due to the entirely different time of existence of the two faunas, but to the fact that the two faunas for long periods of geologic time have occupied separate areas of space on the globe. We can not maintain the idea that during the Oriskanian epoch the genera, and certainly very closely allied species of the genera, which were characteristic of the Hamiltonian fauna did not actually live somewhere and in a flourishing condition and in abundance during the Oriskanian epoch. But they lived in a different sea basin from that in which the characteristic Oriskanian fauna flourished. It is the running together of elements of the two faunas that is anomalous. It is possible to imagine that the dominant species of the Oriskany suddenly became extinct, but not that the dominant species of the Hamilton suddenly came into existence without ancestors.

It is with this point of view that in such a mixed fauna we are forced to use the dominant species in determining the age of the fauna. and to regard the rare and occasional species as indication of the race whose time relations may date back to early Paleozoic time. if not earlier. and forward even to the present time.

SUMMARY OF EVIDENCE

To sum up the evidence, the facts briefly stated are as follows:

In the York River beds at the base of the Gaspé sandstones there is found a number (at least a dozen) of fossils which if found alone would be interpreted as positive evidence of an Oriskanian fauna; associated with these is another lot of fossils, at least as many, which if found alone would be as positive evidence of a Hamiltonian fauna. The sediments were deposited at some particular epoch of the geological time scale. What does this composite fauna signify as to the epoch to which the York River beds belong?

Doctor Clarke in the volume referred to gives the decision in favor of the Hamiltonian epoch, apparently on the ground of the greater number of species identical or closely related to Hamiltonian forms. If we accept his view it follows that the associated Oriskanian forms continued to live on after the epoch of the Oriskanian fauna into Hamiltonian time.

By the interpretation here offered it is assumed that the Hamiltonian types of the fauna are possible ancestors of Hamilton species living in the Oriskanian epoch, which by some movements of the currents of the ocean were brought together in the Acadian province before the revolution which upset the biologic equilibrium of the Oriskanian fauna had completed its work.

The further conclusion is that it was the same events which caused the cessation of the distinctive Oriskanian fauna, which brought into this area the ancestors of the Hamilton species, and that the geologic time of the events was approximately equivalent to the Schoharie epoch of New York state.

The following specific facts seem to corroborate this interpretation:

1. Lower Devonian faunas of the Rhine and Hartz regions of Europe contain a similar combination of species; Rensselærias, Eatonia-like Rhynchonellids, large coarse-ribbed Spirifers, associated with Tropidoleptus, *Grammysia hamiltonensis, Cyrtini heteroclita,* etcetera, to mention but a few striking cases.
2. Tropidoleptus, a prominent representative of the fauna, is already traced downward as far as the typical Oriskany in the Maryland Oriskany.
3. The Nictaux fauna of Nova Scotia and the Moose River sandstone fauna of central and northern Maine, in both of which there is also found *Spirifer arenosus,* show similar admixture of species having close affinity with the Hamiltonian fauna.
4. The upper mass of the breccias of Saint Helens, which contains the Coté Saint Paul species, also has undoubted example of *Spirifer arenosus.*
5. The Nictaux, Moose River, and Upper Saint Helens beds contain dominant Oriskany species as the dominant constituents of their faunas, which taken alone would, I believe, lead any paleontologist acquainted with the faunas to assign them to the Oriskany epoch.
6. The Oriskanian fauna, although intimately associated biologically with the Helderbergian, is in North America biologically quite distinct from the Hamiltonian fauna which is an evolutional expansion of the Onondagaian, and in its dominant elements ceased with the opening of the Onondagaian epoch.
7. The evidence seems convincing that the origin of the Onondaga-Hamiltonian fauna is from a source south of the "Indiana basin" (of Ulrich and

Schuchert), through which it migrated northeastward into the New York area, having at the time the elevated Appalachian land area lying east of it.

8. So far as North America is concerned the Helderberg-Oriskanian fauna appears to have had its origin from the North Atlantic, outside the Appalachian land.

9. To explain the Hercynian-Coblenzian combination in Europe, there appears to have been a mingling of these two general faunas (the Helderberg-Oriskanian and the Onondaga-Hamiltonian), which were more or less distinct on the North American continent.

10. To explain these last three facts seems to require a North Atlantic center of distribution for the Helderberg-Oriskanian fauna, and a South Atlantic or equatorial center of distribution for the Onondagaian fauna.

11. The passage from the Grande Grève limestone into the sandstone and conglomerates of the Gaspé sandstone series indicates an upward movement of that edge of the continent beginning during the life of the Oriskanian fauna, and its remaining above sealevel over the eastern province.

12. The distribution of the Oriskany deposits over New York state indicates a rising of sea bottom into land before the close of Oriskany, or during the time in which the closing Oriskany, the Esopus, and Schoharie grits were being deposited.

13. The coral reefs of the early Onondaga show a depression over New York state and along the Connecticut-Saint Lawrence trough, extending as far east as lake Memphremagog and Chaudière, Quebec, in early Onondagaian time, not, however, depressing the interior province below sealevel, and the trough probably did not reach the North Atlantic basin to the eastward.

14. Although there are indications of the mixed fauna both sides of this trough (to the south in northern Maine and at Gaspé and to the north of it at Saint Helens, Montreal), the faunas of both of these limestones as reported appear to be pure Onondagaian, like the corresponding fauna seen in the more western outcrops with which they are supposed to have been connected.

15. The southern extension of the Onondagaian, in Illinois, Indiana, Kentucky, appears to show closer admixture with types of Helderberg-Oriskanian type than does its northern extension in the New York basin.

Conclusions

These arguments seem to support the hypothesis that the York River beds at Gaspé contain a marine fauna of Oriskanian type not younger in age than the Schoharie grit of New York state. On this hypothesis marine communication with the Atlantic basin must have been cut off with the cessation of that fauna; the upper fauna of Saint Helens and Coté Saint Paul was of not later age than the York River beds at Gaspé; the Onondaga faunas of Owls head and Chaudière entered from the west, having migrated around from the southwest through the Indiana basin, and the Connecticut-Saint Lawrence trough did not open out into the Atlantic basin in Onondagaian time.

The explanation of the mingling of Hamiltonian types with the Oriskanian fauna in this eastern province is found in the meeting of the North Atlantic fauna of Oriskanian type with the South Atlantic fauna of Hamiltonian type, coincident with the rising of the land which caused the continental border of the continent to transgress eastward.

Later the southern fauna found a way into New York through the Indiana basin, but with only such slight admixture of species of the northern fauna as could migrate southward in the Atlantic basin and enter through the Gulf basin into the interior continental basin.

The fundamental correlation principle involved in reaching the above conclusions is that the time relations of a fauna are indicated by its dominant species. At any particular epoch the ancestors of all species which are to become dominant in later ages were living, and in taking samples of a fauna many forms closely related to later species may appear. The dominant elements of the fauna, however, express successful adjustment of the species to the particular environmental conditions, both biological and physical, which mark the epoch of such dominance.

To use a familiar figure, the paleontological record is like a carpet, and the particular species by which we recognize geological epochs are comparable to the threads brought to the surface to make the local pattern. The individual threads are long, however, and if we recognize them before or after the formation in which they form the dominant pattern it is a case of recurrence of the fauna out of its typical time horizon. It is the particular combination of dominant threads which makes up the pattern of each epoch as we know it, and by which the epoch is to be recognized and correlated.

Diastrophism undoubtedly is a fundamental cause in determining the particular pattern of the carpet at each stage in geological history.

DISCUSSION

REMARKS BY CHARLES SCHUCHERT

Doctor Clarke and I together visited the Gaspé section, the only complete one of the Lower Devonian in all eastern America. These formations rest on the upturned black slates of the Ordovician, having about 2,000 feet of limestones and 7,000 feet of sandstones. The section apparently begins with basal New Scotland time, for here we collected *Gypidula galeata* and *Leptœnisca concava*, and then the section continues unbroken into the Middle Devonian. Above these Helderbergian limestones fossils are scarce until near the Grande Grève horizon. In going along the bed of a small stream we were greatly surprised to come upon large surfaces of a crystalline heavy bedded limestone, on which lay *Rhipidomella musculosa*, *Hipparionyx proximus*, and *Rensselæria ovoides*, the three most typical late Oriskanian fossils. On my next visit I located this horizon very exactly, and it is at the base of or even below the Grande Grève zone. Collecting in this limestone reminds one strongly of the true Oriskany of Albany county, New York. The Grande Grève limestone follows, and has many Oriskanian species—in fact, the fauna is more decidedly of this time than of the Onondaga, and yet there are reminders of this Middle Devonian time. These limestones are followed by about 1,000 feet of sandstone in which no fossils occur, and then appears the York River fauna. While collecting these fossils one is impressed with their Hamilton aspect, and one would make this correlation positive were it not for the presence of *Rensselæria ovoides gaspensis*, *Eatonia peculiaris*, *Leptocœlia flabellites*, *Chonostrophia dawsoni*, and *Phacops correlator*. Then all marine faunas cease, and the remainder of the sandstone is probably of continental character.

It is clear, however, that the true Hamilton fauna is not present in the York River beds, because most of the diagnostic brachiopods are absent, even *Tropidoleptus carinatus.* From the character of the Hamilton faunas of Maryland, as described by Professor Swartz, I conclude that they came into this region from the east, and if this is so, then all the more should the typical Hamilton fauna be in the York River beds, if the horizon is of Hamilton time; but it is not there. That this Hamilton fauna was in existence elsewhere long before it appeared in the United States is seen in the western European Coblenzian faunas, and any one must be so impressed on looking at the photograph of a fine Upper Coblenzian slab figured in Frech's Lethæa Geognostica, plate 24*b*. The problem before us is certainly a difficult one.

1. I think Professor Williams takes too broad a view of the Saint Helens fauna. The Hamilton-like fossils are in the agglomerates, and are not associated with the limestone below the agglomerate that seemingly are in place. Those that I collected are rather of Onondaga time than of Hamilton.

2. I do not believe in Professor Williams's principles referred to on page —. We can not in most cases rely on the common dominant species as the true guides for time indicators. It is rather the rarer species. It is this principle of Professor Williams that so many of us object to and which we believe obscures the true chronological significance of the fossils.

3. I do not hold with Doctor Clarke that the Pelecypoda of the Gaspé sandstone (York River zone of Williams) are of decided value in indicating Hamilton time. They may just as well be of Coblenzian time (= Oriskany).

4. The list cited by Williams is certainly striking as of late Lower Devonian time, and more value should, it seems to me, be placed on these than the other fossils of Hamilton aspect.

As the true Oriskany assemblage, however, lies so far beneath—in fact, beneath the Grande Grève limestone—is what leads me to conclude that the York River horizon holds a time above the New York Oriskany. According to my observation, I am disposed to place this horizon definitely in the Onondaga. If Professor Williams thinks it should go near the base of this horizon (= Schoharie) I will not object, nor will I object if Doctor Clarke places the time late in Onondaga, but I would not like to correlate the fauna with the Marcellus.

5. My paleogeographic maps are in harmony with the views here expressed.

6. The true Oriskany is North Atlantic. The Camden chert of Tennessee and Illinois has some of this Hamilton fauna. This is in agreement with faunas of Mæcuro and Ereré. The home of this fauna is South American and the southern Atlantic, and it occurs there as early as Oriskanian time.

7. The Helderberg fauna is of the medial Atlantic. It comes in from the Gulf, and probably also by way of New Jersey. In the Acadian region the faunas are different, with only a few of the medial or southern Atlantic species. Further, this element is unknown in northern Europe, but is widely known in the Mediterranean extensions.

REMARKS BY JOHN M. CLARKE

The point of view taken by Professor Williams impresses me as a very natural one in view of the presence in the Gaspé sandstone fauna of certain leading Lower Devonic species, and this view was indeed that entertained by myself until an intimate acquaintance with the fauna convinced me of what has seemed to me a more trustworthy expression of its relationships. The Hamilton element in this composition is not, I should say, ancestral or merely prenuncial. We have a striking array of species identical in structure with the Hamilton species of New York. I confess the conception "dominant species," on which the speaker lays much weight, is not to me very imperative. I should say that in this case the dominant species are not so much the survivors from the previous fauna as the Hamiltonian assemblage therein, as the latter is dominant, both in respect to actual individual membership and in percentage of the species as a whole. Some of these sandstone species which had been named by Billings—as, for example, *Strophomena blainvilli* and *Spirifer gaspensis*—may yet prove to be actually identical with Hamilton species, and these, together with certain pelecypods, are dominant rather than the survivors. In the study of these eastern American faunas and those of the South American Devonic I have been alive to the disvaluation in time of certain migrants from earlier faunas, especially Tropidoleptus and Vitulina, and it must be nearly twenty years since I laid some stress on the fact that Tropidoleptus had lost its time value in traveling half way around the world.

We must not decline to recognize the Hamiltonian assemblage in the Gaspé sandstone merely because this element of the fauna may not be composed of the commoner species which experience usually associates with typical Hamilton sections. The crux here is not, "What were the old surviving species doing while the Hamilton species were on their way to this region?" (from the southwest, as I conceive) but, as the speaker has stated, "Are the latter really Hamiltonian?" As I have described at some length their points of identity with typical Hamilton fossils, I think we must concede that they are, not ancestrally but actually, Hamiltonian, until each identification has been deliberately controverted. Granted that the species are competent, the age of the fauna must be interpreted in accordance with the latest age represented by its members. This is the recognized correct procedure.

It is gratifying that the speaker is in agreement with the conclusion I have drawn, that the northeast basin is an area of dispersion of the Helderberg and Oriskany faunas southwestward. In defining the Grande Grève formation it was pointed out that its lowest limestone beds carried true Oriskany types, great Hipparionyx, Rensselæria, large Leptostrophias, etcetera, and it has also been shown that these species continue upward in the formation, even to its highest beds, all the time becoming more involved in a prevailing Helderbergian fauna, and with only a few foreshadowings or traces of the Onondaga fauna. Wherever the last element came from, whether on its way out through the Memphremagog passage or on its way in, its representatives are always very primitive in expression.

There is danger before us in this field in attempting to establish a precise correlation in the eastern region with the faunas of the Appalachian basin of Devonic time. In view of the distances involved and the still obscure paleogeographic conditions, such ventures should be cautious and restrained. Approximately equivalent expressions are all that can be expected.

REMARKS BY H. S. WILLIAMS

In reply to the comments made by Professor Schuchert:

1. I am well aware of the difference between the agglomerates (252.1) and

the limestone mass (252.2) of the Saint Helens breccias. The two faunas are quite distinct; that of the limestone is pure Helderbergian; the other, which I have called the Upper Saint Helens (252.1), contains a distinct fauna. It is this Upper Saint Helens which I identify as Oriskanian because of the presence of *Spirifer arenosus* and *Eatonia*. In it occur the species having the strongly Hamiltonian aspect.

2. Regarding the importance of dominant species in determining correlation, I regret that Professor Schuchert can not at present accept the principle. I can only add here that the rare species of a fauna do certainly testify as to its probable connection with another fauna in which the same species are dominant; but a fauna at large is characterized by its dominant species, and until evidence is furnished as to the time range to which its dominant species are restricted the time relations of the fauna are not established.

3. I quite agree with Professor Schuchert's view regarding the Coblenzian significance of the Pelecypods of the York River beds. In my paper I was particularly discussing the correlation with the immediate North American sections.

4. My conclusion that the fauna should be placed at not higher than the age of the Schoharie of New York is determined chiefly by the absence of characteristic Onondagaian species, which have actual representatives in the neighboring Chaudière limestone.

5. I had not seen Professor Schuchert's paleogeographic charts when the paper was written, and am gratified to know that we are in harmony in interpreting the geography of this time.

6 and 7. Professor Schuchert's differentiation in origin between the Helderbergian and Oriskanian faunas is quite consistent with my view. In my interpretation I had classed the Helderbergian with the Oriskanian faunas, distinguishing them from the Onondagaian-Hamiltonian faunas.

I am quite ready to grant that the Helderbergian had its center of distribution farther south than the Oriskanian, but in my grouping them together I referred to the North Atlantic, north of the equator.

If we adopt Professor Schuchert's location of the Helderbergian in a separate center of distribution farther south than the Oriskanian, I think we have good reason for the early appearance of the Oriskanian fauna at the base of the Grande Grève limestone.

In reply to Doctor Clarke's remarks, if we ask the question, "Are the species so called really Helderbergian?" we get only an evasive answer.

Doctor Clarke's claim was that the fauna of the York River beds was equivalent in time to the epoch of the Hamilton formation of New York. I do not deny that the species from the York River beds given names of Hamilton species actually possess the specific character of those species.

My contention is that the paleontologic evidence before us indicates that these "Hamiltonian" species of the York River beds lived and were buried in association with Oriskanian species on the Gaspé peninsula at a time corresponding with the Coblenzian of Europe, and probably not later than the Schoharie beds of New York.

The section adjourned at 12.30 P. M. and met again at 2.15 P. M. with Professor W. B. Clark in the chair.

The following two papers were read by title:

THE AFTONIAN SANDS AND GRAVELS IN WESTERN IOWA

BY BOHUMIL SHIMEK

AN AFTONIAN MAMMALIAN FAUNA

BY SAMUEL CALVIN

Then was presented orally

BRACHIOPODA OF THE RICHMOND GROUP

BY AUGUST F. FOERSTE

[*Abstract*]

In the area dominated by the Cincinnati geanticline there have been several invasions of the brachiopoda considered most typical of the Richmond group. The first of these occurred near the middle of the deposition of the Arnheim bed. The Richmond group of the Mississippi valley, as far as may be determined from a study of the brachiopoda, finds nearer representatives in the upper or Blanchester division of the Waynesville bed and in the Liberty bed than in the Arnheim, Lower Waynesville, or Whitewater beds. A study of the distribution of the brachiopoda in Ohio, Indiana, and Kentucky suggests that the centers of distribution lay more frequently toward the northeast than toward the northwest or west of the present areas of exposure. To account for this, it is imagined that the Richmond group of the Ohio valley was connected with that of the Mississippi valley by way of northern Indiana and Illinois. Possibly, if the areas now covered by overlying formations could be exposed, the Richmond brachiopoda would be found to be absent in southern Indiana and Illinois and in western Kentucky, west of the present areas of exposure of these fossils in the region of the Cincinnati geanticline. Lithological conditions within the areas dominated by this geanticline favor this view.

E. R. Cumings discussed this paper.

After this the following paper was read:

TRAP SHEETS OF THE LAKE NIPIGON BASIN

BY ALFRED W. G. WILSON

This paper has been published as pages 197-222 of this volume.

This paper was discussed by A. W. Grabau, A. W. G. Wilson, A. C. Lane, and A. F. Foerste.

Then was read

RECONNAISSANCE IN ARIZONA AND WESTERN NEW MEXICO ALONG THE SANTA FÉ RAILROAD

BY N. H. DARTON

[*Abstract*]

The reconnaissance was made for the purpose of ascertaining the prospects for deep wells to supply water to the railroad and settlements along its line. The region examined was from ten to forty miles wide, and in this area the principal structural and stratigraphic features of formations from Cambrian to Cretaceous were determined.

This was followed by the reading of

GEOLOGIC STUDIES IN THE ALASKA PENINSULA

BY WALLACE W. ATWOOD[1]

[*Abstract*]

Detailed work was done in the vicinity of Chignik, Balboa, and Herendeen bays and on the island of Unga. The Balboa-Herendeen Bay district was selected as a type area in the peninsula, and detailed studies were pursued in the hope of working out a key to the general geologic conditions of this portion of Alaska.

The formations exposed include the Upper Jurassic, Lower and Upper Cretaceous, marine and fresh-water Eocene, Miocene, possibly some Pliocene and Pleistocene, and recent Kenai plants were found associated with marine invertebrate shells of Upper Eocene age.

Vast quantities of igneous rocks have been intruded into the sedimentary series, and overlying a portion of the area there are volcanic tuffs and basic flows of post-Miocene age.

Coal occurs in the Upper Cretaceous and Eocene. Gold and copper prospects were examined at several localities.

Then was presented orally

PRESENT KNOWLEDGE OF THE OKLAHOMA RED BEDS

BY CHARLES N. GOULD

After this the following paper was read:

FAUNA OF THE FERN GLEN FORMATION

BY STUART WELLER

The paper was discussed by Charles Schuchert, Stuart Weller, and E. O. Ulrich.

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[1] Introduced by A. H. Brooks.

The next two papers were read by title:

AGE AND GEOLOGIC RELATIONS OF THE SANKATY BEDS, NANTUCKET

BY W. O. CROSBY

AGE AND RELATIONS OF THE SANKATY BEDS

BY H. W. SHIMER[1]

Then the following paper was read:

SOME FEATURES OF THE WISCONSIN MIDDLE DEVONIC

BY H. F. CLELAND

[*Abstract*]

This paper gave the results of a study of all the outcrops, as far as known, of the Wisconsin Devonic and their contained faunas. In it were discussed: (1) the relation of the strata to those above and below, (2) the unconformities, (3) the lithological characters, and (4) the character, relationships, and geographical distribution of the faunas.

Charles Schuchert, A. W. Grabau, and H. M. Ami participated in the discussion of this paper.

The next paper read was

ICE-BORNE BOULDER DEPOSITS IN MID-CARBONIFEROUS MARINE SHELLS

BY JOSEPH A. TAFF

[*Abstract*]

Great numbers of boulders and other erratic fragmental rock debris occur in the Caney formation of the Ouachita Mountain region in southeastern Oklahoma. The erratic material consists of boulders, cobbles, and small rock fragments of three general classes, namely: (1) limestones—siliceous, argillaceous, and magnesian; (2) flints, cherts, and (3) quartzites.

The limestones are of various textures and colors, some of which partake of the nature of the quartzites, while others are argillaceous; others yet appear to be dolomitic or perhaps dolomites. Many of the limestone boulders are massive and homogeneous, while others are distinctly stratified and contain two or more classes of limestone or strata of limestone and flint.

Flint and chert boulders are also of common occurrence, and in places are even more abundant than the limestone boulders. Certain of these flints are stratified or bedded and are black or bluish in color, while others are massive, chalcedonic in character, and contain inclusions of drusy quartz. Among these are many of conglomeratic and brecciated nature.

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[1] Introduced by W. O. Crosby.

The third group in the general classification of these erratics includes quartzites of dark and reddish hues.

These erratic boulders vary in size from small pebbles to boulders of enormous size, a few of which attain lengths of more than 50 feet. Many of the smaller boulders are more or less rounded, while a few are quite perfectly so. The larger ones are, as a rule, angular.

At three separate localities in the Ouachita Mountain region certain of the limestone and flint boulders contain grooves and striæ as if produced by the action of shore ice. Certain of these striæ also resemble the markings of slickensided surfaces. The evidence as to the origin of these gouged surfaces is not conclusive.

The erratic boulders contain a comparatively abundant Ordovician and Silurian fauna. The boulders are promiscuously scattered in the Caney formation of black and blue shale with local beds of sandstone in the upper part.

The Caney formation is several hundred feet thick and contains limy concretions or segregations, associated with the erratic boulders and elsewhere, that contain an abundant fauna of late Mississippian or early Pennsylvanian age.

The area of boulder-bearing beds of the Caney formation, as now known, is within the Ouachita Mountain uplift in Oklahoma that extends within a few miles of the Arkansas line to the west end near Atoka. The structure of the region is typically Appalachian, the rocks being closely folded and thrust northward.

On comparison, both lithologically and faunally, the erratic boulders are found to contain identical characteristics in the Cambro-Ordovician and Silurian rocks in the Ouachita Mountain region of Oklahoma and in the Cambro-Ordovician section in north-central Texas. There are evidences of emergence of the rocks of mid-Carboniferous time in the western part of the Arbuckle uplift and in the Texas region to the southwest that affect the Cambro-Ordovician and Silurian rocks. The tentative conclusion is that the boulders were transported from a land to the south by the agencies of ice.

This paper was discussed by David White, W. C. Alden, and J. A. Taff.

The last paper on the sectional programme read was

RELATIONSHIPS OF THE PENNSYLVANIAN AND PERMIAN FAUNAS OF KANSAS AND THEIR CORRELATION WITH SIMILAR FAUNAS OF THE URALS

BY J. W. BEEDE

[*Abstract*]

Owing to physical changes which occurred during the close of Pennsylvanian time, there occurred a great reduction of Pennsylvanian species, followed by the introduction of Permian species. This introduction of new species becomes very noticeable in the Elmdale formation, and its base is considered the base of the Kansas Permian. The Permian, as here understood, includes the Artinskian and "Permo-Carboniferous" of Eurasia.

NINETEENTH ANNUAL REPORT OF THE COMMITTEE ON PHOTOGRAPHS

The Photograph Committee, Mr N. H. Darton, reported that there had been few accessions during the year and practically no use of the collection.

TITLES OF PAPERS PRESENTED BEFORE SECTION E OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

On account of the length of the programme, the Council formed a special section for the consideration of certain papers forming part of a symposium on correlation which had been arranged for by Bailey Willis, chairman, and F. P. Gulliver, secretary, of Section E (geology and geography) of the American Association for the Advancement of Science. For the sake of record the whole list of these papers, with the times when they were read, follows.

Monday, December 28

Pre-Cambrian

11.00 A. M. to 12.10 P. M.

C. R. Van Hise: "Principles of Pre-Cambrian correlation."
F. D. Adams: "The basis of Pre-Cambrian correlation."

Early and Middle Paleozoic

3.30 to 4.00 P. M.

C. D. Walcott: "Evolution of early Paleozoic faunas in relation to their environment."

4.00 to 5.50 P. M.

A. W. Grabau: "Physical and faunal evolution of North America in the late Ordovicic, Siluric, and Devonic time."

4.50 to 5.30 P. M.

Stuart Weller: "Correlation of Middle and Upper Devonian and Mississippian faunas of North America.

Tuesday, December 29

Late Paleozoic

11.00 A. M. to 12.05 P. M.

G. H. Girty: "Physical and Faunal changes of Pennsylvanian and Permian in North America."
David White: "The Upper Paleozoic floras, their succession and range."

Vertebrates

2.00 to 3.15 P. M.

S. W. Williston: "Environmental relations of the early vertebrates."

H. F. Osborn: "Environment and relations of the Cenozoic mammalia."

Mesozoic and Tertiary

3.15 to 4.00 P. M.

T. W. Stanton: "Succession and distribution of later Mesozoic invertebrate faunas."

4.00 to 5.15 P. M.

W. H. Dall: "Conditions governing the evolution and distribution of Tertiary faunas."

Ralph Arnold: "Environment of the Tertiary faunas of the Pacific coast."

WEDNESDAY, DECEMBER 30

Tertiary and Quaternary

10.50 to 11.25 A. M.

F. H. Knowlton: "Succession and range of Mesozoic and Tertiary floras."

11.25 A. M. to 12.25 P. M.

R. D. Salisbury: "Physical geography of the Pleistocene with special reference to conditions bearing on correlation."

D. T. MacDougal: "Origination of self-generating matter and the influence of aridity on its evolutionary development."

2.30 to 3.45 P. M.

T. C. Chamberlin: "Diastrophism as the ultimate basis of correlation."

After the reading of scientific papers had been finished the Society met again in general session, and Dr J. M. Clarke proposed a vote of thanks to the citizens of Baltimore, the authorities of the Johns Hopkins University, and in particular to the members of the department of geology, for the welcome accorded to the Society and the particularly complete arrangements made for the work of the meeting and the comfort and enjoyment of those in attendance. The vote was most heartily passed, and was responded to by Professor W. B. Clark in behalf of the Baltimoreans concerned.

Register of the Baltimore Meeting, 1908

The following Fellows were in attendance at the meeting:

Adams, Frank Dawson
Ami, Henry M.
Arnold, Ralph
Ashley, George Hall
Bain, Harry Foster
Bagg, Rufus Mather, Jr.
Barrell, Joseph
Bascom, Florence
Bassler, Ray Smith
Bayley, William S.
Becker, George F.
Beede, Joshua W.
Berkey, Charles P.
Beyer, Samuel Walker
Bibbins, Arthur B.
Brigham, Albert Perry
Brock, Reginald W.
Calvin, Samuel
Campbell, Henry Donald
Campbell, Marius R.
Case, Ermine C.
Chamberlin, T. C.
Clark, William Bullock
Clarke, John Mason
Cleland, Herdman F.
Clements, J. Morgan
Coleman, Arthur P.
Collier, Arthur J.
Crosby, William O.
Cross, Whitman
Cumings, Edgar R.
Cushing, Henry P.
Darton, Nelson H.
Diller, Joseph S.
Dodge, Richard E.
Emerson, Benjamin K.
Emmons, Samuel F.
Fairchild, Herman L.
Fenneman, Nevin M.
Foerste, August F.
Gilbert, Grove K.
Gordon, Charles H.
Gould, Charles Newton
Grabau, Amadeus W.
Gregory, Herbert E.
Gulliver, Frederick P.
Hague, Arnold
Harris, Gilbert D.
Hayes, C. Willard
Hobbs, William Herbert
Hollick, Arthur
Hovey, Edmund Otis
Howe, Ernest
Howell, Edwin E.
Hubbard, Lucius L.
Huntington, Ellsworth
Iddings, Joseph P.
Jefferson, Mark S. W.
Johnson, Douglas Wilson
Keith, Arthur
Keyes, Charles Rollin
Knowlton, Frank H.
Kraus, Edward Henry
Kümmel, Henry B.
Lane, Alfred C.
Lee, Willis Thomas
Leverett, Frank
Lewis, Joseph Volney
Lindgren, Waldemar
Low, Albert P.
Martin, George Curtis
Mathews, Edward B.

Matthew, W. D.
Mendenhall, Warren C.
Miller, Arthur M.
Miller, Benjamin L.
Miller, Willet G.
Ogilvie, Ida Helen
Osborn, Henry F.
Parks, William A.
Patton, Horace B.
Perkins, George H.
Pratt, Joseph Hyde
Prosser, Charles S.
Purdue, Albert Homer
Reid, Harry Fielding
Rice, William North
Richardson, Charles H.
Ries, Heinrich
Salisbury, Rollin D.
Schrader, Frank C.
Schuchert, Charles
Smith, George Otis
Spencer, J. W.
Stanton, Timothy William
Stevenson, John J.
Taff, Joseph A.
Tarr, Ralph S.
Taylor, Frank B.
Ulrich, Edward O.
Van Hise, Charles R.
Van Horn, Frank Robertson
Vaughn, Thomas Wayland
Walcott, Charles D.
Walker, Thomas L.
Warren, Charles H.
Watson, Thomas L.
Weidman, Samuel
Weller, Stuart
Westgate, Lewis G.
White, David
White, Israel C.
Williams, Henry S.
Willis, Bailey
Williston, Samuel W.
Wilson, Alfred W. G.
Wolff, John E.
Woodward, Robert S.
Wright, Frederick E.
Wright, G. Frederick

And the following Fellows-elect:

Brown, Charles Wilson
Carney, Frank
Fisher, Cassius Asa
Johannsen, Albert
Kay, George Frederick
Richardson, George Burr
Stose, George Willis
Swartz, Charles Kephart

SESSIONS OF THE CORDILLERAN SECTION, AT STANFORD UNIVERITY, CALIFORNIA, WEDNESDAY AND THURSDAY, DECEMBER 30 AND 31, 1908

TITLES OF PAPERS PRESENTED BEFORE THE CORDILLERAN SECTION

SOME FOSSIL FISHES FROM BRAZIL

BY DAVID STARR JORDAN[1]

PYRITE MINES OF LEONA HEIGHTS

BY JOSIAH KEEP[1]

AN OLD BEACH TERRACE IN NEVADA

BY J. CULVER HARTZELL[1]

GEOLOGY OF THE SILVER PEAK QUADRANGLE, NEVADA

BY H. W. TURNER[1]

A REMARKABLE CLAY

BY J. CULVER HARTZELL[1]

EXPERIMENTS WITH A SHAKING MACHINE MADE WITH A VIEW TO DETERMINING THE EFFECT OF WATER UPON LOOSE MATERIAL

BY F. J. ROGERS[1]

COMPARISON OF THE EFFECTS OF THE EARTHQUAKES OF MENDOZO, ARGENTINE REPUBLIC, VALPARAISO, JAMAICA, AND SAN FRANCISCO

BY J. C. BRANNER

GEOLOGY OF SOUTHERN JAPAN

BY ROBERT ANDERSON[1]

PEAT DEPOSITS OF THE LOWER SACRAMENTO AND SAN JOAQUIN RIVERS

BY W. Q. WRIGHT[1]

MINERALS FROM THE COAST RANGES OF CALIFORNIA

BY A. F. ROGERS[1]

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[1] Introduced by J. C. Branner.

DETERMINATION OF MINERALS IN CRUSHED FRAGMENTS BY MEANS OF THE POLARIZING MICROSCOPE

BY A. F. ROGERS[1]

SYNOPSIS OF THE STRATIGRAPHY OF CALIFORNIA

BY JAMES PERRIN SMITH[1]

STRUCTURE OF THE CENTRAL PORTION OF THE COAST RANGES OF CALIFORNIA

BY J. F. NEWSOM

SEDIMENTARY FORMATIONS OF THE COALINGA DISTRICT, CALIFORNIA

BY ROBERT ANDERSON[1]

NEOCENE OF THE UPPER SALINAS VALLEY REGION

BY ROBERT MORAN[1]

RÉSUMÉ OF THE GEOLOGY OF BRAZIL

BY ORVILLE A. DERBY

GEOLOGY OF THE REGION OF DIAMONDS AND CARBONADOS IN BRAZIL

BY J. C. BRANNER

RECONNAISSANCE ABOUT THE BIG SUR REGION OF THE SANTA LUCIA MOUNTAINS

BY J. CULVER HARTZELL[1]

*PROPOSED FORM OF SEISMOGRAPH INTENDED TO GIVE A DIRECT INDICATION OF THE FORCES IN PLAY**

BY W. F. DURAND[1]

[*Abstract*]

(1) The usual forms of seismograph indicate displacement, and if this is recorded on a time axis an analysis of such record may give indications of acceleration and force.

(2) The instrument suggested is intended to give a more direct indication of acceleration and force.

(3) In the usual forms an oscillating system of long period (usually some form of pendulum) is provided with a tracing point, while a roll of paper is mounted on the frame-work and is unrolled under such point. When the system is subjected to a relatively short period disturbance the pendulum remains

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* Manuscript received by the Secretary of the Society February 27, 1909.

[1] Introduced by J. C. Branner.

substantially at rest, while the movement is communicated directly to the frame-work and paper, which thus moves under the tracing point.

(4) The instrument suggested consists of a mass of metal resting on rollers or steel balls, and connected by a thin steel band to a sheet metal diaphragm. This diaphragm forms one boundary of a cell containing water or some other liquid, and is furnished on the opposite side with pipe connection and vertical glass tube. The cell is securely attached to a base plate, and thus to the earth, and hence must share in whatever movement may be imposed on the earth at this point. Through the connection with the diaphragm such movement will also be imposed on the mass of metal referred to (except for the slight yield of the diaphragm), and thus we have a known mass whose motion must necessarily be a close copy of the actual earth movement. This imposed oscillatory motion will develop forces due to the acceleration and retardation of the mass of metal, and these forces will give rise to minute displacements of the diaphragm. These movements by the method indicated may be multiplied one thousand fold or more, and thus made visible as a rise and fall of the liquid in the tube.

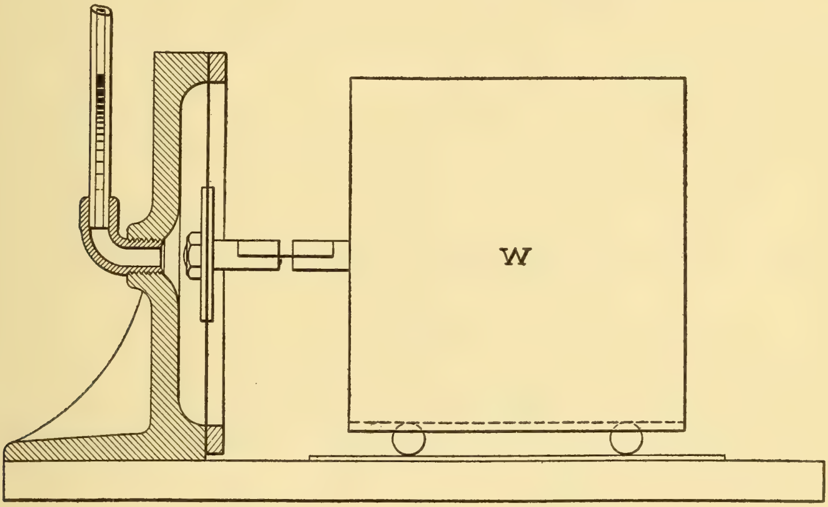

FIGURE 1.—*Proposed Form of Seismograph*

(5) Various means might be employed for registering either the maximum excursion of the liquid or of obtaining a complete registration. These are matters of detail not fully worked out and not important, so far as the main principle of the apparatus is concerned.

(6) The instrument may be made more or less sensitive by varying the thickness of the diaphragm and the diameter of the tube. With easily realized dimensions an ordinate of 3 or 4 inches may be obtained with not to exceed .002 or .003-inch movement of the diaphragm.

(7) By calibration the actual forces in play corresponding to any change in level of liquid are easily determined, and such forces expressed as percentages

of the weight of the mass of metal would furnish a ready and rational basis for rating the intensity of an earthquake shock.

(8) Such an apparatus would naturally give only a single component, such as east or west. As with other forms of seismograph, three units would be required to furnish a complete history of the value and direction of the total force.

(9) The instrument here suggested may possibly by itself be made to give indications of some value regarding maximum intensities, and, taken as supplementary to the record of a displacement seismograph, might serve to give valuable collateral indications regarding the various characteristics of the disturbance.

(10) Preliminary trials with an instrument made up with a special form of diaphragm pressure-gauge indicate results of a hopeful character, and an instrument more definitely planned for seismographic work is now under construction.

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By H. P. Cushing, *Librarian*

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(*a*) *AMERICA*

NEW YORK STATE MUSEUM, **ALBANY**

3426–3429. Museum Reports, no. 60, parts 1-3, and 5.
3460–3461. Museum Reports, no. 61, parts 1 and 3.
3334. Bulletin 123.
3398. Bulletin 124.
3433. Bulletins 125-127.

BOSTON SOCIETY OF NATURAL HISTORY, **BOSTON**

3244. Proceedings, vol. 34, nos. 4-7.

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3374. Anales, serie 3, tomo ix.

CHICAGO ACADEMY OF SCIENCES, **CHICAGO**

3503. Bulletin, vol. 3, no. 1.

CINCINNATI SOCIETY OF NATURAL HISTORY, **CINCINNATI**

3548. Journal, vol. xxi, no. 1.

MUSEO DE LA PLATA. **LA PLATA**

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3371. Anales, segunda serie, tomo i, part 2.

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3443–3445. Boletin, nos. 53-54, 56-69.

INSTITUTO GEOLOGICO DE MEXICO, MEXICO

3304. Parergones, tomo ii, nos. 7-10.
2327. Boletin, num. 17.
3479. Boletin, num. 26.

SOCIEDAD GEOLOGICA MEXICANA, MEXICO

2951. Boletin, tomo 3-4.

AMERICAN GEOGRAPHICAL SOCIETY, NEW YORK

3268. Bulletin, vol. xl, nos. 10-12.

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3442. Bulletin, vol. xxiv.

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3504. Transactions, vol. xxxix, 1908.

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3375. Geology and Mineral Resources of New Brunswick.
3376. Report on Explorations in Nova Scotia in 1907.
3487. Annual Report of the Mineral Production for 1906.
3488. Preliminary Report of the Mineral Production for 1908.
3498. Summary Report of the Geological Survey Branch for 1908.
3499. Preliminary Report on the Gowganda Mining Division.
3500. Iron-ore Deposits of Thunder Bay and Rainy River.
3530. Summary Report of the Mines Branch for 1908.
3531. Report on the Iron-ore Deposits of Nova Scotia.
3532. Mines Branch, Bulletin no. 2.
265. Map Sheets, Nova Scotia, 39, 40, 42, 49-71, 73, 100, 101; British Columbia, Shuswap Sheet; Bancroft, Ont.

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3327. Proceedings, vol. ix, parts 1-3, 1908.

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3226. Proceedings, vol. xlvii, nos. 188-190.

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CALIFORNIA ACADEMY OF SCIENCES, SAN FRANCISCO

3414. Proceedings, fourth series, vol. 3, pp. 1-48.

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3259. Boletin, 2 serie, nos. 2-4, 6.
3415. Carta Geral, Folha de Ouro Fino, Braganca, and S. Bento.

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3449. Annual Report, 1907.

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3465–3467. Professional Papers 57, 58, 60.
3470–3471. Water Supply Papers 195-206.
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3017. Twenty-ninth Annual Report.
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(*b*) *EUROPE*

DEUTSCHE GEOLOGISCHE GESELLSCHAFT, BERLIN

3318. Zeitschrift, band lx, heft 1-4.

KÖNIGLICH PREUSSISCHEN GEOLOGISCHEN LANDESANSTALT UND BERGAKADEMIE, BERLIN

3501. Jahrbuch, band xxvi, 1905.

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3527. Beiträge, lieferung 29, part 2.
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2333. Specialkarten 45, 49, 52; Erlauterungen Nr. 5-8.

R. ACCADEMIA DELLE SCIENZE DELL' INSTITUTO DI BOLOGNA, BOLOGNA

3419. Rendiconto, nuova serie, vol. xi.
3420. Memorie, serie vi, tomo iv.

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3477. Sitzungsberichte und Verhandlungen, 1908.

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3330. Bulletin de la Classe des Sciences, 1908.
3069. Annuaire, 1909.

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3434. Bulletin, tome xxii, fasc. 1-2.
3501. Les Cristallizations des Grottes de Belgique.

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MAGYARHONI FÖLDTANI TARSULAT, BUDAPEST

3339. Földtani közlöny, xxxviii kötet, 1-12 fuset, 1907.

NORGES GEOLOGISKE UNDERSOGELSE, CHRISTIANIA

3359. Report nos. 46-48.
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DET KONGELIGE DANSKE VIDENSKABERNES SELSKAB, COPENHAGEN

3303. Oversigt i Aaret, Förhandlingar 1908, nr. 1-6.
3340, 3516. Shrifter, 7 Raekke, tome vi, no. 3; tome vii, no. 1.

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3230. Sitzungsberichte und Abhandlungen, Jahrgang 1908.

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COMMISSÃO DOS TRABALHOS GEOLOGICOS DE PORTUGAL, LISBON

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BRITISH MUSEUM (NATURAL HISTORY), LONDON

GEOLOGICAL SOCIETY, LONDON

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GEOLOGICAL SURVEY, LONDON

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GEOLOGISTS' ASSOCIATION, LONDON

3065. Proceedings, vol. xx, part 7.
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COMISION DEL MAPA GEOLOGICA DE ESPAÑA, MADRID

SOCIETA ITALIANA DI SCIENZE NATURALI, MILAN

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SOCIÉTÉ IMPÉRIALE DES NATURALISTES DE MOSCOU, MOSCOW

3399. Bulletin, Année 1907.

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2822. Bulletin, vol. xvi, no. 111.
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SOCIÉTÉ GÉOLOGIQUE DE FRANCE, PARIS

3299. Bulletin, 4e série, tome vii, fasc. 9.
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(*c*) *ASIA*

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3313. Philippine Journal of Science, vol. iii.
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(*d*) *AUSTRALASIA*

GEOLOGICAL DEPARTMENT OF SOUTH AUSTRALIA, ADELAIDE

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2445. Reports on recent Mineral Discoveries.

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GEOLOGICAL SURVEY OF NEW ZEALAND, WELLINGTON

3380. Bulletin, new series, nos. 5-6.

(*e*) *AFRICA*

GEOLOGICAL COMMISSION, CAPE TOWN

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3373. Annals of the South African Museum, vol. vii, parts 2-3.

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3366. Transactions, vol. xi, and Proceedings.

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(*B*) FROM STATE GEOLOGICAL SURVEYS AND MINING BUREAUS

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3417. Bulletin, fourth series, no. 9.
3541. Geological Map of Ohio, 1909.

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3486. Third Biennial Report.

OKLAHOMA GEOLOGICAL SURVEY, NORMAN

3435. Bulletin no. 1.

GEOLOGICAL SURVEY OF NEW JERSEY, TRENTON

3555. Annual Report for 1908.

(*C*) FROM SCIENTIFIC SOCIETIES AND INSTITUTIONS

(*a*) *AMERICA*

BROOKLYN INSTITUTE OF ARTS AND SCIENCES, BROOKLYN

2553. Science Bulletin, vol. i, no. 18.
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GEOLOGICAL SURVEY OF BRITISH GUIANA, GEORGETOWN

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ILLINOIS STATE MUSEUM OF NATURAL HISTORY, SPRINGFIELD

3448. Biennial Report, 1908.

(*b*) *EUROPE*

SCHLESISCHE GESELLSCHAFT FÜR VATERLÄNDISCHE CULTUR, BRESLAU

3406. 85 sten Jahresbericht, 1906.

INSTITUTULUI GEOLOGIC AL ROUMANIEI, BUCHAREST

3232. Anuarul, vol. i, fasc. 3.
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3314. Annaes Scientificos, vol. iii, nos. 2-4.
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UNIVERSITY OF UPSALA, UPSALA

3407. Bulletin of the Geological Institution, vol. viii.

GEOLOGISCHE GESELLSCHAFT, WIEN

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(*c*) *ASIA*

TOKYO GEOGRAPHICAL SOCIETY, TOKYO

3382. Journal of Geography, vol. xx, 1908.

IMPERIAL UNIVERSITY OF TOKYO, TOKYO

3545. Journal of the College of Science, vol. xxvi, article 2.

(*D*) FROM FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA (PERSONAL PUBLICATIONS)

BASSLER, R. S.

3425. Cement Materials of Western Virginia.
The Formation of Geodes.
Late Niagaran Strata of West Tennessee.

COSTE, EUGENE

3523. Petroleums and Coals.

CROSS, WHITMAN

3507. Prowerose from Two Buttes, Colorado.
3508. Triassic Portion of the Shinarump Group.
3509. Stratigraphic Results of a Reconnaissance in Western Colorado and Utah.
3510. The Laramie Formation and the Shoshone Group.

GRANT, U. S., AND PURDUE, M. J.

3424. Millbrig Sheet of the Lead and Zinc District of Northwestern Illinois.

HITCHCOCK, C. H.

3416. Geology of the Hanover, N. H., Quadrangle.

WALCOTT, C. D.

3431. Cambrian Geology and Paleontology, no. 5.
Mount Stephen Rocks and Fossils.

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MICHEL MOURLON, BRUSSELS

3552. Nine Separates.

SURVEY OF INDIA, CALCUTTA

3338. Geography and Geology of the Himalaya Mountains and Tibet, parts 1, 4.
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REPUBLICA ORIENTAL DEL URUGUAY, MONTEVIDEO

3524. Annuario Estadistico, tomo i.

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D. EYDOUX AND L. MAURY, PARIS

3533. Les Glaciers orientaux du Pic Long.

H. ARCTOWSKI, WARSAW

3478. Les variations séculaires du Climat de Varsovie.

LIST OF OFFICERS, CORRESPONDENTS, AND FELLOWS

OFFICERS FOR 1909

President:

Grove K. Gilbert, Washington, D. C.

Vice-Presidents:

Frank D. Adams, Montreal, Canada
John M. Clarke, Albany, New York

Secretary:

Edmund Otis Hovey, American Museum of Natural History, New York, N. Y.

Treasurer:

Wm. Bullock Clark, Baltimore, Maryland

Editor:

J. Stanley-Brown, Cold Spring Harbor, Long Island, N. Y.

Librarian:

H. P. Cushing, Cleveland, Ohio

Councilors:

(Term expires 1909)

H. E. Gregory, New Haven, Connecticut
H. F. Reid, Baltimore, Maryland

(Term expires 1910)

H. P. Cushing, Cleveland, Ohio
H. B. Patton, Golden, Colorado

(Term expires 1911)

Geo. Otis Smith, Washington, D. C.
Henry S. Washington, Locust, New Jersey

MEMBERS, DECEMBER 31, 1909

CORRESPONDENTS

CHARLES BARROIS, D. ès Sc., D. Sc., Lille, France. Professor of Geology at the University. December, 1909.

W. C. BRÖGGER, Sc. D., LL. D., Christiania, Norway. Professor of Geology and Mineralogy at the Royal University. December, 1909.

SIR ARCHIBALD GEIKIE, D. C. L., Sc. D., LL. D., Hasslemere, England. President of the Royal Society, late Director General of the Geological Society of the United Kingdom. December, 1909.

ALBRECHT HEIM, D. Sc., Zürich, Switzerland. President of the Swiss Geological Commission and Professor of Geology at the University. December, 1909.

EMANUEL KAYSER, Ph. D., Marburg, Germany. Professor of Geology at the University. December, 1909.

EDUARD SUESS, Ph. D., Vienna, Austria. Formerly Professor of Geology at the Imperial Royal University, President of the Imperial Academy of Sciences. December, 1909.

FERDINAND ZIRKEL, D. Sc., Ph. D., Königstrasse 27, Bonn, Germany. Geheimer Rath, Professor (retired) of Mineralogy and Geology at the University of Leipzig. December, 1909.

FELLOWS

*Indicates Original Fellow (see article III of Constitution)

CLEVELAND ABBE, JR., Ph. D., U. S. Weather Bureau, Washington, D. C. August, 1899.

FRANK DAWSON ADAMS, Ph. D., Montreal, Canada; Professor of Geology in McGill University. December, 1889.

GEORGE I. ADAMS, Sc. D., Bureau of Mines, Manila, P. I. December, 1902.

JOSÉ GUADALUPE AGUILERA, Ph. D., City of Mexico, Mexico; Director del Instituto Geologico de Mexico. August, 1896.

TRUMAN H. ALDRICH, M. E., 1739 P St. N. W., Washington, D. C. May, 1889.

HENRY M. AMI, A. M., Ottawa, Canada; Assistant Paleontologist on Geological and Natural History Survey of Canada. December, 1889.

FRANK M. ANDERSON, B. A., M. S., 2604 Ætna Street, Berkeley, Cal. California State Mining Bureau. June, 1902.

PHILIP ARGALL, 728 Majestic Building, Denver, Colo. August, 1896.

RALPH ARNOLD, Ph. D., 726 H. W. Hellman Bldg., Los Angeles, Cal. December, 1904.

GEORGE HALL ASHLEY, M. E., Ph. D., Washington, D. C.; U. S. Geological Survey. August, 1895.

RUFUS MATHER BAGG, JR., Ph. D., 603 W. Green St., Urbana, Ill.; Instructor in Geology in University of Illinois. December, 1896.

HARRY FOSTER BAIN, M. S., 667 Howard St., San Francisco, Cal. December, 1895.

S. PRENTISS BALDWIN, 736 Prospect St., Cleveland, Ohio. August, 1895.

Sydney H. Ball, A. B., 71 Broadway, New York City. December, 1905.

Erwin Hinckley Barbour, Ph. D., Lincoln, Neb.; Professor of Geology, University of Nebraska, and Acting State Geologist. December, 1896.

Alfred Ernest Barlow, B. A., M. A., D. Sc., 24 Durocheu St., Montreal, Canada. December, 1906.

Joseph Barrell, Ph. D., New Haven, Conn.; Professor of Structural Geology, Yale University. December, 1902.

George H. Barton, B. S., Boston, Mass.; Curator, Boston Society of Natural History. August, 1890.

Florence Bascom, Ph. D., Bryn Mawr, Pa.; Professor of Geology, Bryn Mawr College. August, 1894.

Ray Smith Bassler, B. A., M. S., Ph. D., Washington, D. C.; U. S. National Museum. December, 1906.

William S. Bayley, Ph. D., Urbana, Ill.; Assistant Professor of Geology, University of Illinois. December, 1888.

*George F. Becker, Ph. D., Washington, D. C.; U. S. Geological Survey.

Joshua W. Beede, Ph. D., Bloomington, Ind.; Instructor in Geology, Indiana University. December, 1902.

Robert Bell, I. S. O., Sc. D., M. D., LL. D., F. R. S., Ottawa, Canada; Chief Geologist, Geological Survey, Department of Mines. May, 1889.

Charles P. Berkey, Ph. D., New York City; Instructor in Geology, Columbia University. August, 1901.

Samuel Walker Beyer, Ph. D., Ames, Iowa; Assistant Professor in Geology, Iowa Agricultural College. December, 1896.

Arthur B. Bibbins, Ph. B., Baltimore, Md.; Instructor in Geology, Woman's College. December, 1903.

Albert S. Bickmore, Ph. D., 863 Seventh Ave., New York City; Curator Emeritus, Department of Public Instruction, American Museum of Natural History. December, 1889.

Irving P. Bishop, 109 Norwood Ave., Buffalo, N. Y.; Professor of Natural Science, State Normal and Training School. December, 1899.

Elliot Blackwelder, A. B., Madison, Wis.; Assistant Professor of Geology in University of Wisconsin. December, 1908.

William Phipps Blake, Ph. B., Tucson, Arizona; Director School of Mines, Arizona, and Territorial Geologist. December, 1908.

John M. Boutwell, M. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1905.

John Adams Bownocker, D. Sc., Columbus, Ohio; Professor of Inorganic Geology, Ohio State University. December, 1904.

*John C. Branner, Ph. D., Stanford University, Cal.; Professor of Geology in Leland Stanford, Jr., University.

Albert Perry Brigham, A. B., A. M., Hamilton, N. Y.; Professor of Geology and Natural History, Colgate University. December, 1893.

Reginald W. Brock, M. A., Ottawa, Canada; Director, Geological Survey, Department of Mines. December, 1904.

Alfred Hulse Brooks, B. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1899.

Amos P. Brown, Ph. D., Philadelphia, Pa.; Professor of Mineralogy and Geology, University of Pennsylvania. December, 1905.

Charles Wilson Brown, Ph. D., A. M., Providence, R. I.; Assistant Professor and Head of the Department of Geology in Brown University. December, 1908.

Ernest Robertson Buckley, Ph. D., Rolla, Mo. June, 1902.

*Samuel Calvin, Ph. D., LL. D., Iowa City, Iowa; State Geologist; Professor of Geology in the State University of Iowa.

Henry Donald Campbell, Ph. D., Lexington, Va.; Professor of Geology and Biology in Washington and Lee University. May, 1889.

Marius R. Campbell, Washington, D. C.; U. S. Geological Survey. August, 1892.

Frank Carney, A. B., Granville, Ohio; Professor of Geology in Denison University. December, 1908.

Franklin R. Carpenter, Ph. D., 1420 Josephine St., Denver, Colo. May, 1889.

Ermine C. Case, Ph. D., Ann Arbor, Mich.; Department of Geology, University of Michigan. December, 1901.

*T. C. Chamberlin, LL. D., Chicago, Ill.; Head Professor of Geology, University of Chicago.

Clarence Raymond Claghorn, B. S., M. E., Tacoma, Wash. August, 1891.

Frederick G. Clapp, S. B., 610 Fitzsimmons Bldg., Pittsburgh, Pa. Dec., 1905.

*William Bullock Clark, Ph. D., Baltimore, Md.; Professor of Geology in Johns Hopkins University; State Geologist.

John Mason Clarke, A. M., Ph. D., Albany, N. Y.; State Paleontologist. December, 1897.

Herdman F. Cleland, Ph. D., Williamstown, Mass.; Professor of Geology, Williams College. December, 1905.

J. Morgan Clements, Ph. D., Room 1707, 42 Broadway, New York City. December, 1894.

Collier Cobb, A. B., A. M., Chapel Hill, N. C.; Professor of Geology in University of North Carolina. December, 1894.

Arthur P. Coleman, Ph. D., Toronto, Canada; Professor of Geology, Toronto University, and Geologist of Bureau of Mines of Ontario. December, 1896.

George L. Collie, Ph. D., Beloit, Wis.; Professor of Geology in Beloit College. December, 1897.

Arthur J. Collier, A. M., S. B., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. June, 1902.

*Theodore B. Comstock, Sc. D., Los Angeles, Cal.

Eugene Coste, B. ès-Sc., E. M., Toronto, Canada. December, 1906.

*Francis W. Cragin, Ph. D., Colorado Springs, Colo.; Professor of Geology in Colorado College.

Alja Robinson Crook, Ph. D., Springfield, Ill.; State Museum of Natural History. December, 1898.

*William O. Crosby, B. S., Boston, Mass.; Professor of Geology in Massachusetts Institute of Technology.

Whitman Cross, Ph. D., Washington, D. C.; U. S. Geological Survey. May, 1889.

Garry E. Culver, A. M., 1104 Wisconsin St., Stevens Point, Wis. December, 1891.

Edgar R. Cumings, Ph. D., Bloomington, Ind.; Professor of Geology, Indiana University. August, 1901.

*HENRY P. CUSHING, M. S., Ph. D., Adelbert College, Cleveland, Ohio; Professor of Geology, Western Reserve University.

REGINALD A. DALY, Ph. D., Boston, Mass.; Massachusetts Institute of Technology. December, 1905.

EDWARD SALISBURY DANA, A. B., A. M., Ph. D., 24 Hillhouse Ave., New Haven, Conn.; Professor of Physics and Curator of Mineralogical Collection in Yale University. December, 1908.

*NELSON H. DARTON, Washington, D. C.; U. S. Geological Survey.

*WILLIAM M. DAVIS, S. B., M. E., Cambridge, Mass.; Sturgis-Hooper Professor of Geology in Harvard University.

DAVID T. DAY, Ph. D., Washington, D. C.; U. S. Geological Survey. August, 1891.

ORVILLE A. DERBY, M. S., No. 80 Rua Visconde do Rio Branco, Sao Paulo. Brazil. December, 1890.

*JOSEPH S. DILLER, B. S., Washington, D. C.; U. S. Geological Survey.

EDWARD V. D'INVILLIERS, E. M., 506 Walnut St., Philadelphia, Pa. December, 1888.

RICHARD E. DODGE, A. M., New York City; Professor of Geography in Teachers' College. August, 1897.

NOAH FIELDS DRAKE, Ph. D., Tientsin, China; Professor of Geology in Imperial Tientsin University. December, 1898.

JOHN ALEXANDER DRESSER, B. A., M. A., Ottawa, Ontario, Canada. Geologist, Geological Survey of Canada. December, 1906.

CHARLES R. DRYER, M. A., M. D., Terre Haute, Ind.; Professor of Geography, Indiana State Normal School. August, 1897.

*EDWIN T. DUMBLE, 1306 Main St., Houston, Texas.

CLARENCE EDWARD DUTTON, A. B., Englewood, N. J.; Major, U. S. A. (retired). December, 1907.

ARTHUR S. EAKLE, Ph. D., Berkeley, Cal.; Instructor in Mineralogy, University of California. December, 1899.

CHARLES R. EASTMAN, A. M., Ph. D., Cambridge, Mass.; In Charge of Vertebrate Paleontology, Museum of Comparative Zoology, Harvard University. December, 1895.

EDWIN C. ECKEL, B. S., C. E., Munsey Building, Washington, D. C. December, 1905.

ARTHUR H. ELFTMAN, Ph. D., P. O. Box 601, Tonopah, Nevada. Dec., 1898.

*BENJAMIN K. EMERSON, Ph. D., Amherst, Mass.; Professor in Amherst College.

*SAMUEL F. EMMONS, A. M., E. M., Washington, D. C.; U. S. Geological Survey.

JOHN EYERMAN, F. Z. S., Oakhurst, Easton, Pa. August, 1891.

HAROLD W. FAIRBANKS, B. S., Berkeley, Cal.; Geologist State Mining Bureau. August, 1892.

*HERMAN L. FAIRCHILD, B. S., Rochester, N. Y.; Professor of Geology in University of Rochester.

OLIVER C. FARRINGTON, Ph. D., Chicago, Ill.; Curator of Geology, Field Museum of Natural History. December, 1895.

NEVIN M. FENNEMAN, Ph. D., Cincinnati, Ohio; Professor of Geology, University of Cincinnati. December, 1904.

CASSIUS ASA FISHER, A. B., A. M., 1832 Baltimore St. N. W., Washington, D. C.; U. S. Geological Survey. December, 1908.

August F. Foerste, Ph. D., 417 Grand Ave., Dayton, Ohio; Teacher of Sciences, Steele High School. December, 1899.

William M. Fontaine, A. M., Charlottesville, Va.; Professor of Natural History and Geology in University of Virginia. December, 1888.

Myron Leslie Fuller, S. B., 104 Belmont Ave., Brockton, Mass. December, 1898.

Henry Stewart Gane, Ph. D., Santa Barbara, Cal. December, 1896.

Henry Gannett, S. B., A. Met. B., Washington, D. C.; U. S. Geological Survey. December, 1891.

Russell D. George, A. B., A. M., Boulder, Colo.; Professor of Geology, University of Colorado. December, 1906.

*Grove K. Gilbert, A. M., LL. D., Washington, D. C.; U. S. Geological Survey.

Adam Capen Gill, Ph. D., Ithaca, N. Y.; Assistant Professor of Mineralogy and Petrography in Cornell University. December, 1888.

L. C. Glenn, Ph. D., Nashville, Tenn.; Professor of Geology in Vanderbilt University. June, 1900.

Charles H. Gordon, Ph. D., Knoxville, Tenn.; Professor of Geology and Mineralogy in the University of Tennessee. August, 1893.

Charles Newton Gould, A. M., Norman, Okla.; Professor of Geology, University of Oklahoma. December, 1904.

Amadeus W. Grabau, S. M., S. D., New York City; Professor of Paleontology, Columbia University. December, 1898.

Ulysses Sherman Grant, Ph. D., Evanston, Ill.; Professor of Geology, Northwestern University. December, 1890.

Herbert E. Gregory, Ph. D., New Haven, Conn.; Silliman Professor of Geology, Yale University. August, 1901.

George P. Grimsley, Ph. D., Martinsburg, W. Va.; Assistant State Geologist, Geological Survey of West Virginia. August, 1895.

Leon S. Griswold, A. B., Rolla, Missouri. August, 1902.

Frederic P. Gulliver, Ph. D., Norwichtown, Conn. August, 1895.

Arnold Hague, Ph. B., Washington, D. C.; U. S. Geological Survey. May, 1889.

*Christopher W. Hall, A. M., 803 University Ave., Minneapolis, Minn.; Professor of Geology and Mineralogy in University of Minnesota.

Gilbert D. Harris, Ph. B., Ithaca, N. Y.; Assistant Professor of Paleontology and Stratigraphic Geology, Cornell University. December, 1903.

John Burchmore Harrison, M. A., F. I. C., F. G. S., Georgetown, British Guiana; Government Geologist. June, 1902.

John B. Hastings, M. E., 1480 High St., Denver, Colo. May, 1889.

*Erasmus Haworth, Ph. D., Lawrence, Kans.; Professor of Geology, University of Kansas.

C. Willard Hayes, Ph. D., Washington, D. C.; U. S. Geological Survey. May, 1889.

Richard R. Hice, B. S., Beaver, Pa. December, 1903.

*Eugene W. Hilgard, Ph. D., LL. D., 2728 Bancroft Way, Berkeley, Cal.; Professor of Agriculture in University of California.

Frank A. Hill, Roanoke, Va. May, 1889.

*Robert T. Hill, B. S., 25 Broad St., New York City.

Richard C. Hills, Denver, Colo. August, 1894.

*Charles H. Hitchcock, Ph. D., LL. D., Honolulu, Hawaiian Islands; Professor Emeritus of Geology in Dartmouth College, Hanover, N. H.

William Herbert Hobbs, Ph. D., Ann Arbor, Mich.; Professor of Geology, University of Michigan. August, 1891.

*Levi Holbrook, A. M., P. O. Box 536, New York City.

Arthur Hollick, Ph. D., Bronx Park, New York City; Assistant Curator, Department of Fossil Botany, New York Botanical Garden. August, 1893.

*Joseph A. Holmes, Washington, D. C.; in charge of investigation of fuels and structural materials, U. S. Geological Survey.

Thomas C. Hopkins, Ph. D., Syracuse, N. Y.; Professor of Geology, Syracuse University. December, 1894.

*Edmund Otis Hovey, Ph. D., New York City; Curator of Geology and Invertebrate Paleontology, American Museum of Natural History.

*Horace C. Hovey, D. D., Newburyport, Mass.

Ernest Howe, Ph. D., 75 Kay St., Newport, R. I.; Assistant Geologist, U. S. Geological Survey. December, 1903.

*Edwin E. Howell, A. M., 612 Seventeenth St. N. W., Washington, D. C.

Lucius L. Hubbard, Ph. D., LL. D., Houghton, Mich. December, 1894.

Ellsworth Huntington, A. B., A. M., New Haven, Conn.; Instructor in Geography, Yale University. December, 1906.

Joseph P. Iddings, Ph. B., Chicago, Ill.; Professor of Petrographic Geology, University of Chicago. May, 1889.

John D. Irving, Ph. D., New Haven, Conn.; Professor of Economic Geology, Yale University. December, 1905.

A. Wendell Jackson, Ph. B., 432 Saint Nicholas Ave., New York City. December, 1888.

Robert T. Jackson, S. D., 9 Fayerweather St., Cambridge, Mass.; Assistant Professor in Paleontology in Harvard University. August, 1894.

Thomas M. Jackson, C. E., S. D., Clarksburg, W. Va. May, 1889.

Thomas Augustus Jaggar, Jr., A. B., A. M., Ph. D., Boston, Mass.; Professor of Geology, Massachusetts Institute of Technology. December, 1906.

Mark S. W. Jefferson, A. M., Ypsilanti, Mich.; Professor of Geography, Michigan State Normal College. December, 1904.

Albert Johannsen, B. S., Ph. D., Chicago, Ill.; Department of Geology, University of Chicago. December, 1908.

Douglas Wilson Johnson, B. S., Ph. D., Cambridge, Mass.; Assistant Professor of Physiography, Harvard University. December, 1906.

Alexis A. Julien, Ph. D., New York City; Curator (emeritus) in Geology in Columbia University. May, 1889.

George Frederick Kay, M. A., Iowa City, Iowa; Professor of Mineralogy, Petrography, and Economic Geology in State University of Iowa. December, 1908.

Arthur Keith, A. M., Washington, D. C.; U. S. Geological Survey. May, 1889.

*James F. Kemp, A. B., E. M., New York City; Professor of Geology in Columbia University.

Charles Rollin Keyes, Ph. D., 944 Fifth St., Des Moines, Iowa. August, 1890.

Edward M. Kindle, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1905.

Frank H. Knowlton, M. S., National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. May, 1889.

Edward Henry Kraus, Ph. D., Ann Arbor, Mich.; Junior Professor of Mineralogy, University of Michigan. June, 1902.

Henry B. Kümmel, Ph. D., Trenton, N. J.; State Geologist. December, 1895.

*George F. Kunz, A. M. (Hon.), Ph. D. (Hon.), care of Tiffany & Co., Fifth Ave., at 37th St., New York City.

George Edgar Ladd, Ph. D., Rolla, Mo. August, 1891.

J. C. K. Laflamme, M. A., D. D., Quebec, Canada; Professor of Mineralogy and Geology in Laval University, Quebec. August, 1890.

Henry Landes, A. B., A. M., University Station, Seattle, Wash.; Professor of Geology in University of Washington. December, 1908.

Alfred C. Lane, Ph. D., Tufts College, Mass.; Pearson Professor of Geology in Tufts College. December, 1889.

Andrew C. Lawson, Ph. D., Berkeley, Cal.; Professor of Geology and Mineralogy in the University of California. May, 1889.

Willis Thomas Lee, M. S., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1903.

Charles K. Leith, Ph. D., Madison, Wis.; Professor of Geology, University of Wisconsin; Assistant Geologist, U. S. Geological Survey. December, 1902.

Arthur G. Leonard, Ph. D., Grand Forks, N. Dak.; Professor of Geology and State Geologist, State University of North Dakota. December, 1901.

Frank Leverett, B. S., Ann Arbor, Mich.; Geologist, U. S. Geological Survey. August, 1890.

Joseph Volney Lewis, B. E., S. B., New Brunswick, N. J.; Professor of Geology, Rutgers College. December, 1906.

William Libbey, Sc. D., Princeton, N. J.; Professor of Physical Geography in Princeton University. August, 1899.

Waldemar Lindgren, M. E., Washington, D. C.; U. S. Geological Survey. August, 1890.

George Davis Louderback, Ph. D., Berkeley, Cal.; Associate Professor of Geology, University of California. June, 1902.

Robert H. Loughridge, Ph. D., Berkeley, Cal.; Assistant Professor of Agricultural Chemistry in University of California. May, 1889.

Albert P. Low, B. A. Sc., LL. D., Ottawa, Canada; Deputy Minister, Department of Mines. December, 1905.

Hiram Deyer McCaskey, B. S., Washington, D. C.; U. S. Geological Survey. December, 1904.

Richard G. McConnell, A. B., Ottawa, Canada; Geologist on Geological and Natural History Survey of Canada. May, 1889.

James Rieman Macfarlane, A. B., 100 Diamond St., Pittsburg, Pa. August, 1891.

*W J McGee, LL. D., Washington, D. C.; Inland Waterways Commission.

William McInnes, A. B., Ottawa, Canada; Geologist, Geological and Natural History Survey of Canada. May, 1889.

Peter McKellar, Fort William, Ontario, Canada. August, 1890.

Curtis F. Marbut, A. M., Columbia, Mo.; Professor of Geology in State University and Assistant on Missouri Geological Survey. August, 1897.

Vernon F. Marsters, A. M., Apartado 856, Lima, Peru. August, 1892.

George Curtis Martin, Ph. D., Washington, D. C.; U. S. Geological Survey. June, 1902.

Edward B. Mathews, Ph. D., Baltimore, Md.; Professor of Mineralogy and Petrography in Johns Hopkins University. August, 1895.

W. D. Matthew, Ph. D., New York City; Associate Curator of Vertebrate Paleontology, American Museum of Natural History. December, 1903.

P. H. Mell, M. E., Ph. D., 165 East 10th St., Atlanta, Ga. December, 1888.

Walter C. Mendenhall, B. S., Washington, D. C.; Geologist, U. S. Geological Survey. June, 1902.

John C. Merriam, Ph. D., Berkeley, Cal.; Instructor in Paleontology in University of California. August, 1895.

*Frederick J. H. Merrill, Ph. D., Nogales, Arizona.

George P. Merrill, Ph. D., Washington, D. C.; Curator of Department of Lithology and Physical Geology in U. S. National Museum. December, 1888.

Arthur M. Miller, A. M., Lexington, Ky.; Professor of Geology, State University of Kentucky. December, 1897.

Benjamin L. Miller, Ph. D., South Bethlehem, Pa.; Professor of Geology, Lehigh University. December, 1904.

Willet G. Miller, M. A., Toronto, Canada; Provincial Geologist of Ontario. December, 1902.

Henry Montgomery, Ph. D., Toronto, Canada; Curator of Museum, University of Toronto. December, 1904.

*Frank L. Nason, A. B., West Haven, Conn.

David Hale Newland, B. A., Albany, N. Y.; Assistant State Geologist. December, 1906.

John F. Newsom, Ph. D., Stanford University, Cal.; Associate Professor of Mining in Leland Stanford, Jr., University. December, 1899.

William H. Niles, Ph. D., M. A., Boston, Mass.; Professor Emeritus of Geology, Massachusetts Institute of Technology; Professor of Geology, Wellesley College. August, 1891.

William H. Norton, M. A., Mount Vernon, Iowa; Professor of Geology in Cornell College. December, 1895.

Charles J. Norwood, Lexington, Ky.; Professor of Mining, State University of Kentucky. August, 1894.

Ida Helen Ogilvie, A. B., Ph. D., New York City; Tutor in Geology, Barnard College, Columbia University. December, 1906.

Cleophas C. O'Harra, Ph. D., Rapid City, S. Dak.; Professor of Mineralogy and Geology, South Dakota School of Mines. December, 1904.

Ezequiel Ordoñez, 2 a General Prime, Mexico, D. F., Mex. August, 1896.

*Amos O. Osborn, Waterville, Oneida county, N. Y.

Henry F. Osborn, Sc. D., New York City; President of the American Museum of Natural History. August, 1894.

Charles Palache, B. S., Cambridge, Mass.; Instructor in Mineralogy, Harvard University. August, 1897.

William A. Parks, B. A., Ph. D., Toronto, Canada; Associate Professor of Geology, University of Toronto. December, 1906.

*Horace B. Patton, Ph. D., Golden, Colo.; Professor of Geology and Mineralogy in Colorado School of Mines.

Frederick B. Peck, Ph. D., Easton, Pa.; Professor of Geology and Mineralogy, Lafayette College. August, 1901.

David Pearce Penhallow, B. S., M. S., Sc. D., Montreal, Canada; Professor of Botany in McGill University. December, 1907.

Richard A. F. Penrose, Jr., Ph. D., 460 Bullitt Building, Philadelphia, Pa. May, 1889.

George H. Perkins, Ph. D., Burlington, Vt.; State Geologist; Professor of Geology, University of Vermont. June, 1902.

Joseph H. Perry, 276 Highland St., Worcester, Mass. December, 1888.

Louis V. Pirsson, Ph. D., New Haven, Conn.; Professor of Physical Geology, Sheffield Scientific School of Yale University. August, 1894.

Joseph Hyde Pratt, Ph. D., Chapel Hill, N. C.; Mineralogist, North Carolina Geological Survey. December, 1898.

*Charles S. Prosser, M. S., Columbus, Ohio; Professor of Geology in Ohio State University.

*Raphael Pumpelly, Newport, R. I.

Albert Homer Purdue, B. A., Fayetteville, Ark.; Professor of Geology, University of Arkansas. December, 1904.

Frederick Leslie Ransome, Ph. D., Washington, D. C.; Geologist, U. S. Geological Survey. August, 1895.

Percy Edward Raymond, B. A., Ph. D., Pittsburgh, Pa.; Assistant Curator of Invertebrate Fossils in the Carnegie Museum. December, 1907.

Harry Fielding Reid, Ph. D., Baltimore, Md.; Professor of Geological Physics, Johns Hopkins University. December, 1892.

William North Rice, Ph. D., LL. D., Middletown, Conn.; Professor of Geology in Wesleyan University. August, 1890.

Charles H. Richardson, Ph. D., Syracuse, N. Y.; Assistant Professor of Geology and Mineralogy, Syracuse University. December, 1899.

George Burr Richardson, S. B., S. M., Ph. D., Washington, D. C.; U. S. Geological Survey. December, 1908.

Heinrich Ries, Ph. D., Ithaca, N. Y.; Professor of Economic Geology in Cornell University. December, 1893.

Rudolph Ruedemann, Ph. D., Albany, N. Y.; Assistant State Paleontologist. December, 1905.

Orestes H. St. John, 1141 Twelfth St., San Diego, Cal. May, 1889.

*Rollin D. Salisbury, A. M., Chicago, Ill.; Professor of General and Geographic Geology in University of Chicago.

Frederick W. Sardeson, Ph. D., Minneapolis, Minn.; Assistant Professor of Geology, University of Minnesota. December, 1892.

Thomas Edmund Savage, A. B., B. S., M. S., Urbana, Ill.; Department of Geology, University of Illinois. December, 1907.

Frank C. Schrader, M. S., A. M., Washington, D. C.; U. S. Geological Survey. August, 1901.

Charles Schuchert, New Haven, Conn.; Professor of Paleontology, Yale University. August, 1895.

William B. Scott, Ph. D., 56 Bayard Ave., Princeton, N. J.; Blair Professor of Geology in Princeton University. August, 1892.

Arthur Edmund Seaman, B. S., Houghton, Mich.; Professor of Mineralogy and Geology, Michigan College of Mines. December, 1904.

Henry M. Seely, M. D., Middlebury, Vt.; Professor of Geology in Middlebury College. May, 1889.

Elias H. Sellards, Ph. D., Tallahassee, Fla.; State Geologist. December, 1905.

Joaquim Candido da Costa Seña, Ouro Preto, Brazil; Director of the State School of Mines and Professor of Mineralogy and Geology. December, 1908.

George Burbank Shattuck, Ph. D., Poughkeepsie, N. Y.; Professor of Geology in Vassar College. August, 1899.

Solon Shedd, A. B., Pullman, Wash.; Professor of Geology and Mineralogy, Washington Agricultural College. December, 1904.

Edward M. Shepard, Sc. D., Springfield, Mo.; Professor of Geology, Drury College. August, 1901.

Will H. Sherzer, M. S., Ypsilanti, Mich.; Professor in State Normal School, December, 1890.

Bohumil Shimek, C. E., M. S., Iowa City, Iowa; Professor of Physiological Botany, University of Iowa. December, 1904.

*Frederick W. Simonds, Ph. D., Austin, Texas; Professor of Geology in University of Texas.

William John Sinclair, B. S., Ph. D., Princeton, N. J.; Instructor in Princeton University. December, 1906.

Earle Sloan, Charleston, S. C.; State Geologist of South Carolina. December, 1908.

*Eugene A. Smith, Ph. D., University, Tuscaloosa county, Ala.; State Geologist and Professor of Chemistry and Geology in University of Alabama.

Frank Clemes Smith, E. M., Richland Center, Wis. December, 1898.

George Otis Smith, Ph. D., Washington, D. C.; Director, U. S. Geological Survey. August, 1897.

William S. T. Smith, Ph. D., 839 Lake St., Reno, Nev.; Associate Professor of Geology and Mineralogy, University of Nevada. June, 1902.

*John C. Smock, Ph. D., Trenton, N. J.

Charles H. Smyth, Jr., Ph. D., Princeton, N. J.; Professor of Geology in Princeton University. August, 1892.

Henry L. Smyth, A. B., Cambridge, Mass.; Professor of Mining and Metallurgy in Harvard University. August, 1894.

Arthur Coe Spencer, B. S., Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1896.

*J. W. Spencer, Ph. D., 2019 Hillyer Place, Washington, D. C.

Josiah E. Spurr, A. B., A. M., 165 Broadway, New York City. December, 1894.

Joseph Stanley-Brown, Cold Spring Harbor, Long Island, N. Y. August, 1892.

Timothy William Stanton, B. S., U. S. National Museum, Washington, D. C.; Assistant Paleontologist, U. S. Geological Survey. August, 1891.

*John J. Stevenson, Ph. D., LL. D., 568 West End Ave., New York City.

George Willis Stose, B. S., Washington, D. C.; U. S. Geological Survey. December, 1908.

WILLIAM J. SUTTON, B. S., E. M., Victoria, B. C.; Geologist to E. and N. Railway Co. August, 1901.

CHARLES KEPHART SWARTZ, A. B., Ph. D., Baltimore, Md.; Associate Professor of Geology in Johns Hopkins University. December, 1908.

JOSEPH A. TAFF, B. S., Palo Alto, Cal.; Assistant Geologist, U. S. Geological Survey. August, 1895.

JAMES E. TALMAGE, Ph. D., Salt Lake City, Utah; Professor of Geology in University of Utah. December, 1897.

RALPH S. TARR, Ithaca, N. Y.; Professor of Dynamic Geology and Physical Geography in Cornell University. August, 1890.

FRANK B. TAYLOR, Fort Wayne, Ind. December, 1895.

WILLIAM G. TIGHT, M. S., Albuquerque, N. Mex. August, 1897.

*JAMES E. TODD, A. M., 113 Park St., Lawrence, Kas.; Assistant Geologist, U. S. Geological Survey.

*HENRY W. TURNER, B. S., Room 709, Mills Building, San Francisco, Cal.

JOSEPH B. TYRRELL, M. A., B. Sc., Room 534, Confederation Life Bldg., Toronto, Canada. May, 1889.

JOHAN A. UDDEN, A. M., Rock Island, Ill.; Professor of Geology and Natural History in Augustana College. August, 1897.

EDWARD O. ULRICH, D. Sc., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1903.

*WARREN UPHAM, A. M., Saint Paul, Minn.; Librarian Minnesota Historical Society.

*CHARLES R. VAN HISE, M. S., Ph. D., Madison, Wis.; President University of Wisconsin; Geologist, U. S. Geological Survey.

FRANK ROBERTSON VAN HORN, Ph. D., Cleveland, Ohio; Professor of Geology and Mineralogy, Case School of Applied Science. December, 1898.

GILBERT VAN INGEN, Princeton, N. J.; Curator of Invertebrate Paleontology and Assistant in Geology, Princeton University. December, 1904.

THOMAS WAYLAND VAUGHAN, B. S., A. M., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. August, 1896.

ARTHUR CLIFFORD VEACH, Washington, D. C.; Geologist, U. S. Geological Survey. December, 1906.

*ANTHONY W. VOGDES, 2425 First St., San Diego, Cal.; Brigadier General, U. S. A. (Retired).

*M. EDWARD WADSWORTH, Ph. D., Pittsburgh, Pa.; Dean of the School of Mines in the University of Pittsburgh.

*CHARLES D. WALCOTT, LL. D., Washington, D. C.; Secretary Smithsonian Institution.

THOMAS L. WALKER, Ph. D., Toronto, Canada; Professor of Mineralogy and Petrography, University of Toronto. December, 1903.

CHARLES H. WARREN, Ph. D., Boston, Mass.; Instructor in Geology, Massachusetts Institute of Technology. December, 1901.

HENRY STEPHENS WASHINGTON, Ph. D., Locust, Monmouth Co., N. J.; August, 1896.

THOMAS L. WATSON, Ph. D., Charlottesville, Va.; Professor of Geology in University of Virginia. June, 1900.

WALTER H. WEED, E. M., Norwalk, Conn. May, 1889.

FRED. BOUGHTON WEEKS, Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1903.

SAMUEL WEIDMAN, Ph. D., Madison, Wis.; Geologist, Wisconsin Geological and Natural History Survey. December, 1903.

STUART WELLER, B. S., Chicago, Ill.; Associate Professor of Paleontologic Geology, University of Chicago. June, 1900.

LEWIS G. WESTGATE, Ph. D., Delaware, Ohio; Professor of Geology, Ohio Wesleyan University.

THOMAS C. WESTON, care of A. Patton, Levis, Quebec, Canada. August, 1893.

DAVID WHITE, B. S., U. S. National Museum, Washington, D. C.; Geologist, U. S. Geological Survey. May, 1889.

*ISRAEL C. WHITE, Ph. D., Morgantown, W. Va.

*ROBERT P. WHITFIELD, A. M., New York City; Curator Emeritus of Geology and Invertebrate Paleontology, American Museum of Natural History.

FRANK A. WILDER, Ph. D., North Holston, Smyth Co., Va. December, 1905.

*EDWARD H. WILLIAMS, JR., A. C., E. M., Andover, Mass.

*HENRY S. WILLIAMS, Ph. D., Ithaca, N. Y.; Professor of Geology and Head of Geological Department, Cornell University.

IRA A. WILLIAMS, M. Sc., Ames, Iowa; Teacher Iowa State College. December, 1905.

BAILEY WILLIS, Washington, D. C.; U. S. Geological Survey. December, 1889.

SAMUEL W. WILLISTON, Ph. D., M. D., Chicago, Ill.; Professor of Paleontology, University of Chicago. December, 1889.

ARTHUR B. WILLMOTT, M. A., 24 Adelaide St., W., Toronto, Canada. December, 1899.

ALFRED W. G. WILSON, Ph. D., Mines Branch, Department of Mines, Ottawa, Canada. June, 1902.

ALEXANDER N. WINCHELL, Doct. U. Paris, Madison, Wis.; Professor of Geology and Mineralogy, University of Wisconsin. August, 1901.

*HORACE VAUGHN WINCHELL, 505 Palace Building, Minneapolis, Minn.

*NEWTON H. WINCHELL, A. M., 501 East River Road, Minneapolis, Minn.

*ARTHUR WINSLOW, B. S., 131 State St., Boston, Mass.

JOHN E. WOLFF, Ph. D., Cambridge, Mass.; Professor of Petrography and Mineralogy in Harvard University and Curator of the Mineralogical Museum. December, 1889.

JOSEPH E. WOODMAN, S. D., New York City; Professor of Geology in New York University. December, 1905.

ROBERT S. WOODWARD, C. E., Washington, D. C.; President of the Carnegie Institution of Washington. May, 1889.

JAY B. WOODWORTH, B. S., 24 Langdon St., Cambridge, Mass.; Assistant Professor of Geology, Harvard University. December, 1895.

FREDERIC E. WRIGHT, Ph. D., Washington, D. C.; Geophysical Laboratory, Carnegie Institution. December, 1903.

*G. FREDERICK WRIGHT, D. D., Oberlin, Ohio; Professor in Oberlin Theological Seminary.

GEORGE A. YOUNG, Ph. D., Ottawa, Canada; Geologist, Geological Survey of Canada. December, 1905.

FELLOWS-ELECT

WILLIAM CLINTON ALDEN, A. B., A. M., Ph. D., Washington, D. C. Assistant Geologist, U. S. Geological Survey. December, 1909.

WALLACE WALTER ATWOOD, B. S., Ph. D., Chicago, Illinois. Instructor at University of Chicago and Assistant Geologist, U. S. Geological Survey. December, 1909.

EDSON SUNDERLAND BASTIN, A. B., A. M., Washington, D. C. Assistant Geologist, U. S. Geological Survey. December, 1909.

EDWARD WILBER BERRY, Baltimore, Maryland. Instructor in Paleontology, Johns Hopkins University. December, 1909.

WILLIS STANLEY BLATCHLEY, A. B., A. M., State House, Indianapolis, Indiana. State Geologist of Indiana. December, 1909.

HENRY ANDREW BUEHLER, B. S., Rolla, Missouri. State Geologist of Missouri. December, 1909.

FRED HARVEY HALL CALHOUN, B. S., Ph. D., Clemson College, South Carolina. Professor of Geology and Mineralogy, Clemson College, and Assistant Geologist, U. S. Geological Survey. December, 1909.

ARTHUR LOUIS DAY, B. A., Ph. D., Washington, D. C. Director, Geophysical Laboratory, Carnegie Institution of Washington. December, 1909.

FRANK WILBRIDGE DE WOLF, S. B., Urbana, Illinois. Assistant State Geologist of Illinois and Assistant Geologist, U. S. Geological Survey. December, 1909.

JAMES WALTER GOLDTHWAIT, A. B., A. M., Ph. D., Hanover, New Hampshire. Assistant Professor of Geology in Dartmouth College and head of department. December, 1909.

BAIRD HALBERSTADT, Pottsville, Pennsylvania. Engineer and Geologist. December, 1909.

OSCAR H. HERSHEY, Kellogg, Idaho. December, 1909.

FREDERICK BREWSTER LOOMIS, B. A., Ph. D., Amherst, Massachusetts. Professor of Comparative Anatomy in Amherst College. December, 1909.

RICHARD SWANN LULL, B. S., M. S., Ph. D., New Haven, Connecticut. Assistant Professor of Vertebrate Paleontology, Yale University. December, 1909.

GEORGE ROGERS MANSFIELD, B. S., A. M., Ph. D., Evanston, Illinois. Assistant Professor of Geology, Northwestern University. December, 1909.

LAWRENCE MARTIN, A. B., A. M., Madison, Wisconsin. Instructor in Geology, University of Wisconsin. December, 1909.

SAMUEL WASHINGTON MCCALLIE, Ph. B., Atlanta, Georgia. State Geologist of Georgia. December, 1909.

WILLIAM JOHN MILLER, S. B., Ph. D., Clinton, New York. Professor of Geology and Mineralogy in Hamilton College. December, 1909.

MALCOLM JOHN MUNN, Washington, D. C. Assistant Geologist, U. S. Geological Survey. December, 1909.

EDWARD ORTON, JR., E. M., Columbus, Ohio. Assistant Geologist, Geological Survey of Ohio. December, 1909.

PHILIP S. SMITH, A. B., A. M., Ph. D., Washington, D. C. Assistant Geologist, U. S. Geological Survey. December, 1909.

WARREN DU PRÉ SMITH, B. S., A. M., Ph. D., Manila, Philippine Islands. Chief of the Mining Bureau. December, 1909.

CYRUS FISHER TOLMAN, JR., B. S., Tucson, Arizona. Professor of Geology and Mining in the University of Arizona. December, 1909.

CHARLES WILL WRIGHT, B. S., M. E., Washington, D. C. Assistant Geologist, U. S. Geological Survey. December, 1909.

FELLOWS DECEASED

*Indicates Original Fellow (see article III of Constitution)

*Charles A. Ashburner, M. S., C. E. Died December 24, 1889.
Charles E. Beecher, Ph. D. Died February 14, 1904.
Amos Bowman. Died June 18, 1894.
*J. H. Chapin, Ph. D. Died March 14, 1892.
*Edward W. Claypole, D. Sc. Died August 17, 1901.
George H. Cook, Ph. D., LL. D. Died September 22, 1889.
*Edward D. Cope, Ph. D. Died April 12, 1897.
Antonio Del Castillo. Died October 28, 1895.
*James D. Dana, LL. D. Died April 14, 1895.
George M. Dawson, D. Sc. Died March 2, 1901.
Sir J. William Dawson, LL. D. Died November 19, 1899.
*William B. Dwight, Ph. B. Died August 29, 1906.
*George H. Eldridge, A. B. Died June 29, 1905.
*Albert E. Foote. Died October 10, 1895.
*Persifor Frazer. Died April 7, 1909.
*Homer T. Fuller. Died August 14, 1908.
N. J. Giroux, C. E. Died November 30, 1890.
*James Hall, LL. D. Died August 7, 1898.
John B. Hatcher, Ph. B. Died July 3, 1904.
*Robert Hay. Died December 14, 1895.
*Angelo Heilprin. Died July 17, 1907.
David Honeyman, D. C. L. Died October 17, 1889.
Thomas Sterry Hunt, D. Sc., LL. D. Died February 12, 1892.
*Alpheus Hyatt, B. S. Died January 15, 1902.
*Joseph F. James, M. S. Died March 29, 1897.
Wilbur C. Knight, B. S., A. M. Died July 28, 1903.
Ralph D. Lacoe. Died February 5, 1901.
Daniel W. Langton. Died June 21, 1909.
*Joseph Le Conte, M. D., LL. D. Died July 6, 1901.
*J. Peter Lesley, LL. D. Died June 2, 1903.
Henry McCalley, A. M., C. E. Died November 20, 1904.
Oliver Marcy, LL. D. Died March 19, 1899.
Othniel C. Marsh, Ph. D., LL. D. Died March 18, 1899.
James E. Mills, B. S. Died July 25, 1901.
*Henry B. Nason, M. D., Ph. D., LL. D. Died January 17, 1895.
*Peter Neff, M. A. Died May 11, 1903.
*John S. Newberry, M. D., LL. D. Died December 7, 1892.
*Edward Orton, Ph. D., LL. D. Died October 16, 1899.
*Richard Owen, LL. D. Died March 24, 1890.
Samuel L. Penfield. Died August 14, 1906.
*Franklin Platt. Died July 24, 1900.
William H. Pettee, A. M. Died May 26, 1904.
*John Wesley Powell, LL. D. Died September 23, 1902.
*Israel C. Russell, LL. D. Died May 1, 1906.
*James M. Safford, M. D., LL. D. Died July 3, 1907.

*Charles Schaeffer, M. D. Died November 23, 1903.
*Nathaniel S. Shaler, LL. D. Died April 10, 1906.
Charles Wachsmuth. Died February 7, 1896.
Theodore G. White, Ph. D. Died July 7, 1901.
*George H. Williams, Ph. D. Died July 12, 1894.
*J. Francis Williams, Ph. D. Died September 9, 1891.
*Alexander Winchell, LL. D. Died February 19, 1891.
Albert A. Wright, Ph. D. Died April 2, 1905.
William S. Yeates. Died February 19, 1908.

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